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PRACTICAL MECHANICS

APPLIED TO

THE REQUIREMENTS OF THE SAILOR

BY

THOMAS MACKENZIE

MASTER MARINER, FELLOW OF THE ROYAL ASTRONOMICAL SOCIETY
ETC.

FOURTH EDITION

WITH NUMEROUS ILLUSTRATIONS

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EDITOR'S PREFATORY NOTE.

THIS SERIES has been designed to meet the growing desire on the part of Officers in the Mercantile Marine for a MORE SCIENTIFIC INSIGHT into the principles of their profession, and the sciences upon which the Art of Navigation is founded. The treatises are, for the most part, WRITTEN BY SAILORS FOR SAILORS; and, where this is not the case, by authors who have special knowledge of the subjects dealt with and their application to the Sailor's life. The treatment is thoroughly scientific, yet as free as possible from abstruse technicalities, and the style such as will render it easy for the young sailor to gain a knowledge of the elements of his profession by private reading and without difficulty.

E. B.

LONDON, *April* 1896.

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AUTHOR'S PREFACE.

NOTWITHSTANDING the existence of many able Text-books on Practical and Applied Mechanics, few are adapted in their application to the requirements of the Sailor, and many young men, feeling the need of a work on this subject, have expressed a desire for a text-book on Mechanics suited to their own special wants, and such as shall enable them to conduct their professional operations in this field of practice on more scientific principles than have hitherto obtained on board ship in the Mercantile Marine.

The Author has, therefore, been encouraged to make an attempt to supply this want, and can but hope that he has succeeded in laying before his brother-sailors, in a simple and easily comprehended manner, the principles upon which the mechanical devices employed by seamen are founded. He trusts that the sailor-student will find no difficulty in grasping and applying these principles to other mechanical systems which he may be called upon to adopt, but which may not have been specially dealt with in the text.

The Author begs to express his thanks for drawings of special machines to Messrs. Tangye & Co., engineers, Birmingham; Messrs. Harfield & Co., engineers, London;

Messrs. Redpath & Paris, engineers, London; and Messrs. Bullivant & Co., steel wire-rope makers, London; to Messrs. Robt. Duncan & Co., shipbuilders, Port-Glasgow, and Captain Edward Blackmore for the sail-plans of two modern sailing-vessels; to Lieutenant Huddleston, R.I.M., for the sketch of the Rhine ferry-boat; and, finally, to the publishers for the use of several illustrations of beams, &c.

T. M.

NAUTICAL SCHOOL,
48 FENCHURCH STREET, LONDON, E.C.
April 1896.

PUBLISHER'S NOTE TO THE FOURTH EDITION.

YET another edition of this book is called for, proving that however the subject may be dreaded by the sailor, a great company of men have benefited from its pages, and it is evident that the simple and fascinating treatment of the subject by the author has been appreciated, and no doubt will continue to be of service.

October 1916.

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PRACTICAL MECHANICS

APPLIED TO THE REQUIREMENTS OF THE SAILOR.

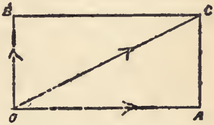
CHAPTER I.

RESOLUTION AND COMPOSITION OF FORCES.

The Parallelogram of Forces.—If two forces act upon the same point of a body, it is always possible to find a single force whose effect shall be the same as the combined effect of the two given forces. This substitution of one force for two others is called the *composition* of forces, and if one force be resolved into two others it is called the *resolution* of forces.

Resolution and Composition of Forces.—Let OA and OB be the directions and magnitudes of two forces acting on the point O; draw BC parallel to OA and AC parallel to OB; this completes the parallelogram; from O, the point at which the forces are applied, draw the diagonal OC, then OC will represent in direction and magnitude a single force which produces the same effect as the forces OA and OB combined.

FIG. 1.



Parallelogram of Velocities.—Suppose O to be a particle which starts moving from the point O in the direction OA, and when it reaches A then moves in the direction AC, reaching C in the same time that it took to move from O to A. The diagonal OC will represent in magnitude and direction a velocity which would have carried the particle to C in half the time which it took to move along OA, AC. Now suppose the velocities OA and OB combined in the motion of the particle O when it starts from the point at O, it will move in the direction OC, and will reach the point C in the same time that it would take to move from O to A or from A to C, therefore the diagonal OC is the resultant of the combined velocities OA and OB.

A familiar example of the resultant of two velocities is when a vessel is steered across a river in a direction at right angles to the bank; the point at which she reaches the opposite bank will be considerably below the point opposite to that from which she started; this distance below the opposite point will represent the component velocity of the stream, while the breadth of the river will represent the component velocity of the vessel; the line joining the point of departure with the point of arrival will represent the resultant of the two velocities, and will be the real track made by the vessel.

Geometrical Solution.—The representation of forces by right lines, as in Fig. 1, has the advantage of exhibiting both direction and magnitude. Selecting any unit of length, such as an inch, a foot, or any other convenient scale unit, draw a line in the direction OC of the given force containing as many units of length as there are units of force or weight in OC. Suppose the direction OC is measured by the angle AOC; at the point O draw a line perpendicular to the line OA, and complete the parallelogram OBCA, and the lines OB and OA will contain as many units of length as there are units of weight in the forces OB,OA, which by their combined action would produce the same effect as the single force OC.

When it is required to resolve a single force into two components without respect to their directions, they are always resolved at right angles to each other.

Solution by the Traverse Tables.—The Traverse Tables afford a ready means of solving the parallelogram of forces. Let the magnitude OC and direction AOC of a force be given (Fig. 1). Enter the Traverse Table with AOC as a course, and OC as a distance; in the departure column will be found AC, and in the difference of latitude column OA, the two component forces.

If OA and OB had been given acting at right angles to each other, to find the direction and magnitude of the resultant OC.—Find in the Traverse Table OA in a diff. lat. column, OB in a dep. column; the distance corresponding to these will be the magnitude of OC, and the course will be its direction with respect to OA.

Example I.—Let a force acting in the direction AC equal 10 tons; make an angle of 18° with the line OA; required the magnitude of the components OB and OA.

In the Traverse Table 18° as a course and 10 in the distance column give dep OB = 3·1 tons, and diff. lat. OA = 9·5 tons.

Example II.—Suppose OA to be a boom or outrigger, and OC a topping-lift supporting the end O, and making the angle AOC = 25°: a weight of 8 tons is supported at the point O; required the strain on the topping-lift OC and the thrust on the boom OA.

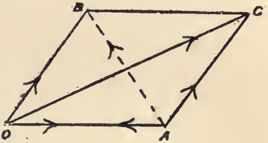
In the figure the angle AOC is the course; therefore AC is a dep. and OA a diff. lat. With 8 tons as a dep. and 25° as a course, the Traverse Table gives as diff. lat. OA 17·2 tons thrust on the boom, and as dist. OC 19 tons for strain on the topping-lift.

Practical Examples.—Example III.—What would be the strain on the main lift when the yard is square and a weight of 2 tons is hanging to a tackle hooked at the lift band; the lift makes an angle of 22° with the yard?

22° as a course and 2 tons in a dep. column give in a distance column $5\frac{1}{3}$ tons strain on the lift.

In the foregoing cases the component forces have been considered as acting at right angles to each other. We will now introduce the oblique parallelogram of forces. Let two forces, OA and OB, be inclined to each other at an acute angle BOA; lay off on OB and OA as many units of length as there are units of weight in their respective forces, and complete the parallelogram OBCA; the diagonal OC will represent the resultant in magnitude and direction.

Fig. 2.



Suppose, again, two forces inclined to each other at an obtuse angle OAC, acting at the point A in the direction AC and AO, complete the parallelogram, as before, and the resultant will be the diagonal AB.

To solve these two cases by the Traverse Table.—Consider the line OA as a meridian, and the inclination of OB to it as a course; with the force OB as a distance, find the diff. lat. and dep. to this course, and form a traverse, considering OA as a distance to a course 0°; as there will only be one dep., add together the diff lats.; enter the traverse table with this sum in a diff. lat. column and the dep. in a dep. column, the corresponding distance will be the resultant, and the course will be its inclination to the line which was taken as a meridian.

In the second case, when the angle made by the two forces with each other is obtuse, or greater than 90°, take the supplement for a course, and form a traverse as before, only take the difference between the diff. lats. for a diff. lat.; with this and the dep. find the course and dist., which will be the inclination and magnitude of the resultant to the force taken in the meridian.

When the component forces are inclined to each other by an angle less than 90°, add the diff. lats. in the traverse; but when inclined to each other by an angle greater than 90°, take the difference of the diff. lats. in the traverse.

Example IV.—Two forces, $OB = 5$ tons and $OA = 7$ tons, act at the point O, inclined to each other at an angle of 53°. Required the magnitude and inclination of the resultant OC to the force OA.

OA	course	0°	dist.	7	d. lat	7	dep.	0
OB	,,	53°	,,	5	,,	3	,,	4
					,,	10	,,	4

10 in the diff. lat. column and 4 in the dep. gives in a dist. column 11 tons as resultant, inclined 22° to OA.

Example V.—Two forces, $AO = 7$ tons and $AC = 5$ tons, act at the point A, inclined to each other at an angle of 127°. Required the resultant AB and its inclination to AO.

Take the supplement of 127° = 53°

AO	course	0°	dist.	7	d. lat.	7	dep.	0
AC	,,	53°	,,	5	,,	3	,,	4
						4		4

Here the diff. lat. and dep. are equal, hence the inclination of the resultant AB to AO is seen at once to be 45°, and the traverse gives the resultant 6 tons nearly.

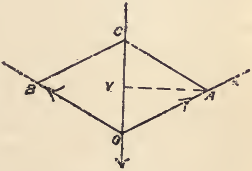
Example VI.—Suppose BO and OA the two legs of a span, and the angle that they make with each other $BOA = 58°$. A weight of 12 tons is supported at O, acting in the direction CO, making an angle of 24° with the leg OA, and 34° with the leg OB. Required the strains upon the legs of the span OB and OA.

By Construction.—Draw a line OA; from the point O draw OB, making an angle of 58° with OA; again from O draw a line OC, making an angle of 24° with OA; on OC lay off 12 units of any scale, taken, say, from the longitude scale of any chart; through this point on the diagonal draw a line parallel to OA, and another parallel to OB; this completes the parallelogram, and the sides OB and OA represent the strains upon the legs of the span. (See Fig. 2, which, when drawn to scale, makes $OC = 12$ tons, $OB = 5\frac{3}{4}$ tons, $OA = 8$ tons.)

Example VII.—A span hanging in a vertical plane is capable of bearing a strain of 30 tons; what weight will it support in the middle when each leg makes the same angle with a plumb line, and the angle between the two legs is equal to 130°?

By Construction.—Draw a vertical line. From any point on this line draw a line inclined upwards at an angle of 65° from the vertical line to the right, and from the same point draw another line at the same angle to the left of the vertical line; these two lines represent the legs of the span. From any scale lay off 30 units upon one of the legs and complete the parallelogram; the diagonal will represent the weight the span is capable of supporting. AO, BO are the legs of the span; completing the parallelogram to OA = 30 tons, gives OC = 25·4 tons.

Fig. 3.



By the Traverse Table.—Take half the angle between the legs of the span 65° as a course, then the weight upon the span, 30 tons in a distance column will give in a diff. lat. column 12·7 tons, which is half the weight the span will support; therefore the span will bear 25·4 tons.

In Fig. 3 OC is the resultant to the two forces OB, OA, each = 30 tons. A perpendicular from A upon OC divides OC into two equal parts at V; and taking VOA 65° as a course, with OA as the distance, give OV as a diff. lat., which is equal to half the resultant.

Example VIII.—A weight of 14 tons has to be supported by a span whose legs are inclined to each other at an angle of 150°. Required the weight on the span.

By the Traverse Table.—Take half 150° = 75° as a course, and half the weight, 7 tons, as a diff. lat.; against these in a distance column is 27 tons, the weight on the span.

Example IX.—Let a derrick be inclined to the horizon at an angle of 48°; the topping-lift is at right angles to the derrick, and a weight of 18 tons is supported at the derrick head. Required the weight on the topping-lift and the thrust on the derrick.

In this example the derrick represents the diagonal or resultant of the parallelogram; the weight one side, and the topping-lift the other.

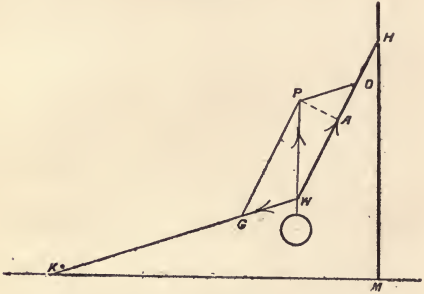
By Construction.—Draw a line inclined to the horizontal 48° to represent the derrick, from the upper end draw a line upwards at right angles to it to represent the topping lift, from the same point on the derrick draw a line perpendicular to the horizontal to represent the weight; on this line lay off 18 units and complete the parallelogram; the other side is the weight on the lift, and the diagonal is the thrust on the derrick.

By the Traverse Table.—Since the derrick is inclined 48° to the horizon, the weight which hangs perpendicular is inclined 42° to the derrick, and the topping-lift is at right angles to it. Therefore, with 42° as a course, and 18 tons as a distance, we get in a dep. column 12 tons, the weight on the topping-lift, and in a diff. lat. column 13·4, the thrust on the derrick. In this example the topping-lift, being at right angles to the derrick, neither relieves nor increases the thrust.

As the topping-lift of a derrick may lead upwards or downwards from the derrick-head, the easiest method of solution is by construction; since when the position of the heel is known by measurement from the mast and from the point plumbed by the tackle, together with the length from heel to purchase-block and the height on the mast at which the topping-lift is hooked or lashed, the solution by construction becomes quite easy.

Example X.—A pennant at the topmast-head is guyed forward

FIG. 4.



over the fore-hatch by another pennant from the gin to the knight-heads. What will be the weight upon the mast-head pennant and upon the guy when the mast-head pennant makes an angle of 26° with the mast, and the guy makes an angle of 140° with the pennant, while a weight of three tons is hanging in the gin?

By Construction.—Draw HM to represent the mast; at an angle of 26° to HM draw HW; from W draw WK, making an angle of 140° with HW; from W draw a perpendicular line WP, containing 3 units to any scale; complete the parallelogram by drawing through P the lines PG and PO parallel to OW and GW respectively; then OW will be the weight on the pennant, and GW that on the guy. When drawn to scale the weight on OW is found to be 4 tons, and on OP or WG 2 tons.

By the Traverse Table.—The angle OWG = 140°, and OWP = 26°. Therefore PWG = 140° − 26° = 114°, but WPO = PWG, hence the angle POW = 40°. Let fall the perpendicular PA on OW. With PW as a distance and 26° as a course find the dep. PA and diff. lat. WA. Next, with this departure in a dep. column and 40° as a course find the dist. PO and diff. lat. OA, to which add AW for the weight WO on the pennant; the distance PO will be the weight on the guy:

Course.	Dist.	D. Lat.	Dep.
26°	3	2·7	1.3
40°	2 = PO	1·5	1·3
		4·2 = WO	

Weight on the guy 2 tons. Weight on the pendant 4·2 tons.

CHAPTER II.

WORK DONE BY MACHINES.

Work done by Machines.—In all machines the *work done* is less than the *work applied;* this loss is due to friction, and is represented by the difference between the *work applied* and the *work done.* The efficiency of a machine may always be found by noting the distances through which the power and resistance or weight move; these are in the same proportion as the power to the resistance in a machine without friction; hence the difference between the theoretical resistance and that actually overcome by a given power will be the loss of power due to friction.

In a lever, if the power moves through a distance of 4 feet while the resistance moves through 6 inches—

power × 48 inches = resistance × 6 inches.

Therefore the resistance is eight times the power.

In the crab winch, the product of the power applied to the handle into the distance through which it moves is equal to the product of the resistance into the distance through which it is raised—

power × distance travelled = resistance × distance travelled.

In tackles, the power in the threefold purchase will travel 6 feet for every foot the weight is raised, therefore

power × distance travelled = weight × distance raised.

In the inclined plane the power moves over the slant length of the plane while the weight is only raised through the height of the plane, therefore:—

power × length of plane = weight × height of plane.

In the screw, the power moves through the circumference of the circle described by the bar to which the power is applied, while the weight moves through the distance between two threads, therefore:—

power × circumference of circle = weight × distance between the thread.

Hence the purchase of a machine may be practically ascertained by simply noting that the spaces passed over by any two points of the machine in the same time will give the proportion of the forces acting at these points.

It is generally stated that "what is gained in time is lost in power;" or the converse, that "what is gained in power is lost in time;" or that all parts of a machine do the same amount of *work*, for if any point moves with a greater force than another, it must move slower, since the equality of *moments* is constant, no matter how complicated the system may be; therefore, if any number of points be taken in a machine, the products of the distances through which they move in the same time into the forces acting at these points will all be the same.

WORK DONE BY A FORCE.

Work done by Force such as Manual Labour.—The *work done* by a force is expressed by the weight *lifted* through a given height by the force, and is therefore the product of the weight multiplied by the height—

$$\text{work done} = \text{weight} \times \text{height}.$$

This is evidently true, because the work is proportional to the weight raised, and also to the height to which it is raised; if either of these be changed, the work is changed in the same proportion, and is therefore proportional to the product of the weight and the height to which it is raised.

The English *unit of work* is the power necessary to raise one pound through a space of one foot. Thus, if 1 lb. be raised 1 foot by a living agent or a machine, then 1 unit of work has been done; if 1 lb. be raised 15 feet, then 15 units of work have been performed; if 10 lbs. have been raised through 12 feet, then $10 \times 12 = 120$ units of work have been performed, and so on. Therefore, the work done by a power is equal to the power multiplied by the height, *i.e.*,

$$\text{work done} = \text{power} \times \text{height}.$$

Suppose the power to be 140 lbs. and the height 30 feet—

$$\text{then work done} = 140 \times 30 = 4200 \text{ lbs.}$$

these are called *foot-pounds*, and may be expressed as 4200 lbs. raised through 1 foot, or 1 lb. through 4200 ft.

Now supposing this to be the work which a particular agent is capable of performing in one minute. Then we have the work done in one minute = 4200 foot-pounds, therefore if the power applied is 100 lbs. we get the height to which it is raised $= \frac{4200}{100} = 42$ feet, or we may take the height to be 20 feet and we get for the weight raised $\frac{4200}{20} = 210$ lbs.

For the purpose of applying these principles to the work of living agents, the labouring force or work of man must vary according to the manner in which he exerts his strength. The following table is taken from Baker's *Statics*, and gives the work done per minute when the duration of labour is 8 hours per day:—

WORK DONE PER MINUTE.

Standard Units of Work done per Minute.—

Duration of labour, eight hours per day.

A man	turning a winch	2600	units or foot-pounds.
,,	drawing horizontally . . .	3200	,, ,,
,,	raising materials with a single block	1600	,, ,,
,,	throwing materials to the height of 5 feet	560	,, ,,

EXAMPLE I.—How many tons of coals will a man heave up to a height of 26 feet working with a single winch for 8 hours?

Here the time of work is $8 \times 60 = 480$ minutes; therefore, by the table, units of work per day $= 2600 \times 480$ foot-pounds.

As this is the product of the weight and the height to which it is raised, divide by 26 feet the height the weight is raised.

Therefore, $\frac{2600 \times 480}{26} = \frac{1248000}{26} = 48000$ lbs.

$$\frac{48000}{2240} = 21 \cdot 4 \text{ tons per day of 8 hours.}$$

EXAMPLE II.—How many tons of ballast will 4 men working two winches discharge in a day of 8 hours, when the height to which the baskets must be raised is 18 feet?

The table gives 2600 foot-pounds per minute per man, therefore each man raises $\frac{2600}{18}$ lbs. per minute.

Therefore 4 men raise $\frac{2600 \times 4}{18}$ lbs. per minute.

Weight raised per day of 8 hours $= \frac{2600}{18} \times 4 \times 8 \times 60 =$

$$144 \cdot 4 \times 1920.$$

Divide this by 2240 $\therefore \frac{144 \cdot 4 \times 1920}{2240} = 123 \cdot 8$ tons.

EXAMPLE III.—How many tons of coal will 4 men raise out of a ship's hold to the height of 16 feet, working by means of *paddy's ways*,* during a day of 8 hours?

---

* *Paddy's ways* consist of a sort of ladder or grid rigged up at one of the hatchways, having four or five rungs, which can be mounted by four

This case comes under the units of work done with a single block.

Therefore one man will raise in 1 minute $\frac{1600}{16} = 100$ lbs.

And in a day $60 \times 8 \times 100 = 48{,}000$ lbs.

As there are 4 men, the number of tons raised will be

$$\frac{48000 \times 4}{2240} = 85{\cdot}7 \text{ tons.}$$

This plan of discharging coal is that practised in sailing-colliers in the *Pool*, and the average work is about 10 tons per hour to every gang of 4 men.

Example IV.—How many hours would it take to discharge a ship of 1000 tons of coals, working 5 gangs of 4 men each with *paddy's ways*, the gangs being relieved every 8 hours, and the average height to which the coal must be raised being 16 feet?

Here the work done by 1 man per minute = 1600 (see table).

Therefore, weight raised by 1 man per minute = $\frac{1600}{16} = 100$ lbs., and per hour $100 \times 60 = 6000$ lbs.

In 5 gangs there are 20 men; therefore, the total quantity of coal raised per hour is $6000 \times 20 = 120{,}000$ lbs.

Therefore, $\frac{120000}{2240} = 53{\cdot}12$ tons per hour.

Therefore, $\frac{1000 \text{ tons}}{53{\cdot}12} = 18{\cdot}8$ hours.

Example V.—How many days will it require to discharge from a ship 1800 tons of coal, working with three hand-winches and two men to each winch for 8 hours per day, and raising the coal to the average height of 14 feet?

Coal raised per man per minute = $\frac{2600}{14} = 185{\cdot}6$ lbs.

Therefore 1 man raises per day $185{\cdot}6 \times 60 \times 8 = 185{\cdot}6 \times 480$ lbs., and since there are 6 men, $89{,}088 \times 6$ = total weight raised per day; therefore $\frac{89088 \times 6}{2240} = 238{\cdot}6$ tons.

Therefore, $\frac{1800}{238{\cdot}6} = 7{\cdot}5$ days.

Example VI.—How many men will be required to hoist by

---

men at a time; each man holds a rope attached to the whip, two or three rungs are mounted, two long pulls are taken, and then the men jump off backwards, bringing the hands down to the knees, a movement which raises the basket high enough.

means of hand-winches 2000 tons of coal from a ship's hold, where the average hoist is 20 feet, in 6 days working 10 hours per day?

Here $\frac{2000}{6} = 333\frac{1}{3}$ tons to be discharged per day.

Now one man will raise $\frac{2600}{20} \times 60 \times 10 = 78{,}000$ lbs. per day or $\frac{78000}{2240} = 34{\cdot}8$ tons.

Therefore $\frac{333{\cdot}33}{34{\cdot}8} = 9{\cdot}6$ men, which would mean 10 men.

Therefore, since there are 2 men to each winch, 5 winches would be required.

In all such work due regard must be paid to the load put upon the hoist, for if it is too heavy the men will soon fag. And it is more economical to reduce the load to suit the power of the gang than to increase the gang by another man; for instance, four men upon two winches will do more work with light loads, than four men on one winch with a heavy load; and in jumping with gangs of two or four men, an even number of men on the ropes will do better than an odd number with a heavier load, such as increasing the load of four men and putting five men on the ways or ropes.

CHAPTER III.

THE MECHANICAL POWERS.

The Mechanical Powers reduced to two.—The six mechanical powers are: the *Lever,* the *Wheel and Axle,* the *Pulley,* the *Inclined Plane,* the *Wedge,* and the *Screw.*

The first three may be reduced to the lever, and the last three may be referred to the inclined plane. So that we really must reckon on only *two* simple mechanical powers.

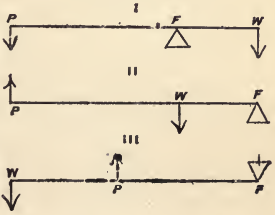
When two forces act upon each other by means of machinery, one of them is called the *power* and the other the *weight.* The resistance to be overcome is the weight, and the force which is used to overcome that resistance is called the power.

THE LEVER.

Description of the Lever.—The *lever* is a rigid bar capable of motion about a fixed point called the *fulcrum.* The parts of the *lever* into which the *fulcrum* divides it are called the *arms* of the *lever.* When the *arms* are in the same straight line, it is called a *straight lever;* otherwise, a *bent* lever.

Three Orders of the Lever.—There are three kinds of straight lever, depending upon the position of the points to which the power and resistance or weight are applied with respect to the *fulcrum.*

FIG. 5



In the *first* kind the *fulcrum* F is between the *power* P and the *weight* W.

In the *second* kind the power P and the weight W are on the same side of the *fulcrum,* but the weight is between the *fulcrum* and the power.

In the *third* kind the weight and power are also on the same side of the *fulcrum,* but the power is between the *fulcrum* and the weight.

Levers of the First Kind.—Levers of the first kind are crowbars, handspikes, pincers, scissors, &c.

Levers of the Second Kind.—Levers of the second kind are boats' oars, where the water is the *fulcrum* and the rowlock the resistance.

Levers of the Third Kind.—Levers of the third kind are such as tongs, sheep shears, and the bones of animals, in which the joint is the *fulcrum*, the muscle near the joint is the *power*, and the force exerted by the limb at a greater distance from the joint is the weight.

In the first kind of lever the *power* is to the *weight* as the *short arm* of the lever is to the *long arm*.

$$P : W :: FW : FP$$

And from this we learn that the *weight* multiplied by its distance from the *fulcrum* is equal to the *power* multiplied by its distance from the *fulcrum*.

$$P \times FP = W \times FW$$

Moments of the Lever.—These are called the *moments* of the *power* and the *weight*, and are always equal when the lever is in equilibrium.

In the second kind of lever,

$$P : W :: FW : FP$$

Hence as in the first kind,

$$P \times FP = W \times FW$$

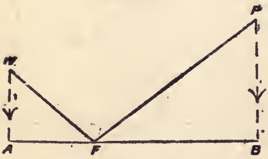
In the third kind $P : W :: FW : FP$

Therefore $P \times FP = W \times FW$

So that in all the levers the *moment* of the weight is equal to the *moment* of the power when the machine is in equilibrium.

The sum of the *power* and the *weight* is called the *resultant*, and represents the pressure on the *fulcrum* in a lever of the first kind. In levers of the second and third kind, the *resultant* or pressure upon the *fulcrum* is the difference between the *power* and the weight.

FIG. 6.



Description of the Bent Lever.—The *bent* lever is represented in Fig. 6, where F is the fulcrum, FW and FP the two arms. The *weight* acts in the direction WA and the *power* in the direction PB, therefore AF is the perpendicular distance of the *weight* from the *fulcrum*, and FB the perpendicular distance of the *power* from the same point.

Therefore $P : W :: AF : FB$
And $P \times FB = W \times AF =$ the *moments.*

To find the Position of the Fulcrum when the Weights and the Distances between them are given.—Since in the lever the *power* is to the *weight* in the inverse proportion of the length of the arms, and the resultant or pressure on the fulcrum is equal to the sum of the *weight* and the power in the first kind of lever, we may find the position of the *fulcrum* when the distance between the power and the weight is given.

Rule.—*As the sum of the power and the weight is to the distance between the power and the weight, so is the weight to the distance of the fulcrum from the power.*

$$\text{Dist. of fulcrum from P} = \frac{\text{Weight} \times \textit{dist. between power and weight}}{\text{Sum of } \textit{power} \text{ and } \textit{weight}}$$

In a lever of the second kind the weight being between the *fulcrum* and the power and the pressure on the fulcrum equal to the difference between the weight and the power: we may find the distance of the *fulcrum* from the weight when the *power* and weight with the distance between them are given.

Rule.—*As the difference between the power and weight is to the power, so is the distance between the power and weight to the distance of the fulcrum from the weight.*

$$\text{Distance of fulcrum from W} = \frac{\text{Power} \times \textit{dist. between power and weight}}{\text{Diff. of } \textit{power} \text{ and } \textit{weight}}$$

In a lever of the third kind the power is between the *fulcrum* and the weight; therefore to find the distance of the *fulcrum* from the power when the *power* and *weight,* with the distance between them, are given.

Rule.—*As the difference between the power and the weight is to the weight, so is the distance between the power and weight to the distance of the fulcrum from the power.*

$$\text{Dist. of fulcrum from P} = \frac{\text{Weight} \times \textit{dist. between power and weight}}{\text{Diff. of } \textit{power} \text{ and } \textit{weight}}$$

Examples. Example I.—A lever of the first kind is 6 feet in length, the fulcrum 4 feet from the power and 2 feet from the weight; what weight will a power of 2 cwt. raise?

2 feet : 4 feet :: 2 cwt. : weight.

$$\text{Weight} = \frac{4 \times 2}{2} = 4 \text{ cwt.}$$

Example II.—What power will be required to raise a weight of a ton at 2 feet from the fulcrum when the power is applied at 7 feet from the fulcrum?

$$\text{Power} : 20 \text{ cwt} :: 2 \text{ feet} : 7 \text{ feet}.$$

Therefore,

$$\text{Power} = \frac{20 \times 2}{7} = 5\tfrac{5}{7} \text{ cwt}.$$

Example III.—In a lever of the second order, what power will be required to raise a weight of 10 cwt. placed at 18 inches from the *fulcrum* and $6\frac{1}{2}$ feet from the power?

The power is 8 feet from the fulcrum, therefore,

$$\text{Power} : 10 \text{ cwt.} :: 1{\cdot}5 \text{ feet} : 8 \text{ feet}.$$

$$\text{Power} = \frac{1{\cdot}5 \times 10}{8} = \frac{15}{8} = 1\tfrac{7}{8} \text{ cwt}.$$

Examples of a Number of Distributed Weights.

Example IV.—In a lever of the first kind a number of weights are distributed along the rod on one side of the fulcrum as follows:

At 6 feet	from the fulcrum	40 lbs.
„ 3 „	„ „	30 „
„ $1\frac{1}{2}$ „	„ „	50 „
„ $\frac{1}{2}$ „	„ „	60 „

Required the weight which will balance them at the distance of 2 feet on the opposite side of the fulcrum; also find the position of a weight equal to the sum of the distributed weights on the same side of the fulcrum.

Rule.—*Multiply each weight by its distance from the fulcrum and add the products together. This gives the moment of the weights which is equal to the moment of the power; divide this moment by the distance of the power from the fulcrum. The quotient is the power required.*

$$\begin{array}{rrcrcr}
 & \text{Ft.} & & & & \\
\text{Moment of weight} = & 6 & \times & 40 & = & 240 \\
 & 3 & \times & 30 & = & 90 \\
 & 1\frac{1}{2} & \times & 50 & = & 75 \\
 & \frac{1}{2} & \times & 60 & = & 30 \\
\hline
 & \text{Sum of weights} = & & 180 & & 435 = \text{sum of } \textit{moments}.
\end{array}$$

$$\frac{\text{Sum of moments}}{\text{dist. of power}} = \frac{435}{2} = 217{\cdot}5 \text{ lbs.} = \text{the balancing power.}$$

To find the Position of a Weight equal to the Sum of the Weights which will balance the same Power.

Rule.—*Divide the sum of the moments by the sum of the weights. The quotient is the distance from the fulcrum at which the sum of the weights will produce the same effects as when distributed.*

$$\frac{\text{Sum of } \textit{moments}}{\text{Sum of weights}} = \frac{435}{180} = 2 \text{ feet } 5 \text{ inches from the fulcrum.}$$

Example V.—Two men are carrying a cask of provisions weighing 224 lbs. upon a handspike. The distance between the points where the handspike rests on their shoulders is 6 feet, and the cask hangs at a point 1 foot from the middle. Required, the weight each man will support on his shoulders Here the weight is 4 feet from one man and 2 feet from the other. Therefore, calling the men *a* and *b*—

As the whole length : the weight :: the dist. from *a* : weight on *b*
6 : 224 :: 4 : weight on *b*

$$\text{Weight on } b = \frac{224 \times 4}{6} = \frac{896}{6} = 149\tfrac{1}{3} \text{ lbs.}$$

Therefore the weight on $a = 224 - 149\frac{1}{3} = 74\frac{2}{3}$ lbs.

Example VI.—A main yard is 40 feet from the slings to the lift; on a tackle at 12 feet inside the lift is hanging a weight of $1\frac{1}{2}$ tons. Required, the weight on the slings, and the perpendicular weight at the lift.

Here the weight is 28 feet from the slings and 12 feet from the lift, therefore,

$$40 : 30^c :: 28 : \text{weight on lift.}$$

$$\text{Weight on lift} = \frac{30^c \times 28}{40} = \frac{3 \times 28}{4} = 21 \text{ cwt.}$$

And,

$$40 : 30 :: 12 : \text{weight on slings.}$$

$$\text{Weight on slings} = \frac{3 \times 12}{4} = 9 \text{ cwt.}$$

The sum of the two is 30 cwt., or $1\frac{1}{2}$ tons.

Example VII.—A piece of machinery rests on deck at a distance of 12 feet from the stringer and 8 feet from the midship stanchions, its weight is 7 tons; what weight will the stringer and stanchions have to bear respectively?

Here the distance between the stringer and the stanchions is 20 feet, therefore,

$$20 : 7 :: 12 : \text{weight on the stanchions.}$$

$$\text{Weight on stanchions} = \frac{7 \times 12}{20} = \frac{84}{20} = 4\tfrac{1}{5} \text{ tons.}$$

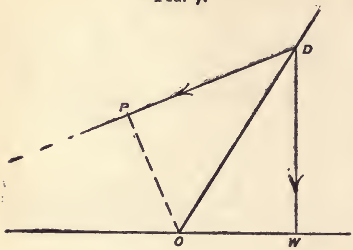
Therefore the weight on the stringer is $7 - 4\frac{1}{5} = 2\frac{4}{5}$ tons.

It will be seen that the three cases just given are examples of levers of the second kind, since the weight is situated between what may be considered the fulcrum and the power.

The Bent Lever on board ship usually takes the form of derricks or shears, but it may be applied in finding the strain upon the lift of a yard when hoisting in weights, or upon the stays of a mast, which is supporting a derrick, &c. &c.

Example of the Bent Lever in a Derrick. EXAMPLE VIII.—A derrick is 40 feet in length, and the tackle plumbs a point 16·9 feet from the heel; the topping-lift is inclined downwards at an angle of 76° to the derrick. Required, the strain upon the topping-lift when 15 tons are hanging to the derrick-head.

FIG. 7.



In Fig. 7 let OD = 40 feet, OW 16·9, the angle ODP between the derrick and topping-lift = 76°.

O is considered the fulcrum, OW is the perpendicular distance of the weight from the fulcrum, and represents the effective length of the arm OD; OP is at right angles to the topping-lift, and represents the effective arm upon which the topping-lift acts, hence the derrick takes the form of the bent lever DO, and the imaginary arm PO; but the effective arm of DO is also imaginary, since it is represented by OW; therefore the arms upon which the topping-lift and the weight are acting at right angles are PO, WO; therefore the equality of *moments* gives:

$$\text{Weight} \times \text{WO} = \text{PO} \times \text{weight on topping-lift},$$

$$\text{therefore,}\quad \text{Weight on topping-lift} = \frac{\text{weight} \times \text{WO}}{\text{PO}}$$

PO being at right angles to PD, we have a right-angled triangle with the angle PDO = 76°, and the side OD = 40, to find PO:

Enter the traverse table with course 76°, dist. 40, and find in dep. column PO = 38·8, therefore,

$$\text{Weight on topping-lift} = \frac{15 \times 16{\cdot}9}{38{\cdot}8} = 6\tfrac{1}{2} \text{ tons nearly.}$$

Example of the Bent Lever in a Yard. EXAMPLE IX.—The fore yard is employed to hoist in an anchor, which, including the strain on the fall of the tackle, puts a weight of two tons at the lift band, while the yard is square by the lifts, which make an angle of 26° with the yard. From the lift band to the slings is 40 feet. Required, the strain on the lift.

Here the slings of the yard is the fulcrum, and the *bent* lever is formed by the yard and a perpendicular to the lift from the slings; this imaginary arm is found by taking the yard-arm as a distance, the angle it makes with the lift as a course, and finding in the traverse table the departure.

Course 26° dist. 40 gives dep. = 17·5.

Now, by equality of *moments*,

$$2 \times 40 = 17{\cdot}5 \times \text{strain on lift.}$$

Therefore,

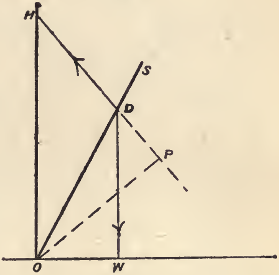
$$\text{Strain on lift} = \frac{2 \times 40}{17{\cdot}5} = 4{\cdot}6 \text{ tons nearly.}$$

Which shows that when the lift is inclined to the yard by such a small angle as 26° the strain on it becomes double the weight lifted.

Example X.—A derrick is 38 feet from the heel to the purchase block, and the tackle plumbs a point 24 feet from the heel; the topping-lift leads upwards, making an angle of 68° with the derrick, which supports a weight of 16 tons. Required the strain on the topping-lift.

In Fig. 8 let OH be the mast, OD the derrick, OW the distance of the weight from the heel which is the effective length of OD; HD is the topping-lift, which extend below the derrick to P, and draw OP perpendicular to it; OP and OW represent the two arms of the bent lever, and O is the fulcrum; OW is given, and OP is easily found, since in the right-angled triangle ODP, OD the length of the derrick together with the angle PDO are given—because PDO = HDS; to find OP:

Fig. 8.



Enter the traverse table with 68° as course, 38 as distance, and find in dep. column, OP = 35·2.

And by the equality of *moments*,

$$\text{Weight} \times \text{OW} = \text{strain on lift} \times \text{OP}$$

$$16 \times 24 = \text{strain on lift} = 35{\cdot}2$$

Therefore,

$$\text{Strain on lift} = \frac{16 \times 24}{35{\cdot}2} = 11 \text{ tons nearly.}$$

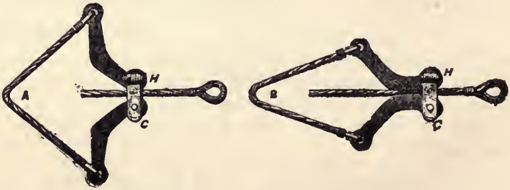
When the angle under the topping-lift, between it and the derrick, is greater than a right angle, the perpendicular OP will always be on the same side of the derrick as the weight. When the same angle is less than a right angle the perpendicular on the topping-lift will be on the opposite side to the weight. When the topping-lift is at right angles to the derrick the derrick becomes one of the effective arms of the bent lever.

A useful application of the lever is when an ordinary cargo truck, such as is used for running cargo along ships' decks and along quays, is improvised as a crowbar for raising and breaking out heavy packages in a ship's hold or 'tween decks. The bill at the head of the truck is forced under the package, and then the handles of the truck are borne down upon by as many men as can get at them, and while kept low the truck is dragged upon, bringing the package with it; when another truck can be got to the other side of the package, it is eased down upon some pieces of wood, and when both too large and too heavy for one truck, the bill of the other truck is thrust under the side opposite to the first one, and the handles of both being borne down the package is wheeled to the hatchway or any desired position.

The negroes on the Isthmus of Panama are such adepts at using the cargo truck as a crowbar, that the latter is never used in working cargo, and they just as readily pick up and transport a package of machinery weighing several tons by means of their trucks as they would *tackle* a Manchester bale of 15 cwt., nor has the author ever seen them defeated by any weight up to 12 tons; with such a heavy weight they simply surround and swarm it with trucks, and, as long as the latter are strong enough to take the weight, it is picked up and carried off.

The truck used in the hold as a crowbar saves a great deal of damage to the cargo, for it cannot be unnecessarily used as a crowbar might, and it can only be applied in one way—*i.e.*, under

FIG. 9.



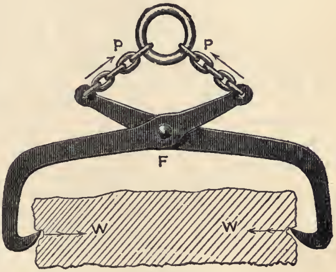
Bullivant & Co's Nippers London.

the package, which seldom or never injures the package owing to the large extent of its surface of application.

Bent Lever.—An application of the bent lever is shown in the accompanying illustration (Fig. 9) of Bullivant's portable nippers for quickly checking steel-wire hawsers. Figure A shows the nipper when open to allow the rope to pass through. C is a clamp hinged on one arm at H, having a round hole at the other end, which goes over a stud on the other arm at C when the rope has been entered between the arms. When the wire strop attached to the arms is placed over a bollard, and the arms let go from the position A, the nippers take the position B and choke their own luff. The greater the strain on the rope the harder they grip.

Another application of the bent lever is the ice dog or grip largely used for discharging ice from a vessel's hold. In the illustration (Fig. 10) PP shows the directions of the forces on the shorter arms by which the dogs hang to the winch rope. F is the fulcrum to both arms, and WW show the directions of the gripping forces on the block of ice between the dogs. Instead of hooked grips, which are liable to split heavy ice blocks, flat plates having rasped surfaces are substituted at the gripping ends of the arms, but a surge on the winch is liable to cause them to slip.

FIG. 10.



ICE DOGS.

These dogs are also used for dragging timber into and out of ships' holds, and for hauling it up the landing-slips.

CHAPTER IV.

THE WHEEL AND AXLE.

Description of the Wheel and Axle.—The *wheel and axle* is a simple and useful modification of the first kind of lever.

FIG. 11.

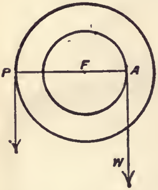


Fig. 11 is a cross section of the *wheel and axle;* PF is the radius of the wheel and FA the radius of the *axle,* W is the weight or resistance at the circumference of the *axle,* and P the power at the circumference of the wheel. It is evident, then, that—

$$P : W :: FA : FP$$

RULE.—*As the power is to the weight, so is the radius of the axle to the radius of the wheel.*

The form which this machine takes on board ship is the hand-winch used by corn-porters, ballast men and coal-heavers, where the handles represent the wheel of which they are the radii and the barrel is the axle. The capstan is also a form of the *wheel and axle,* the bars being the radii of the wheel.

Examples. EXAMPLE I.—In a hand-winch the radius of the handle is 14 inches and the radius of the barrel is 3 inches; and allowing half an inch for the thickness of the rope; what weight will two men heave up when each exerts a force of 21 lbs. on the handles?

$$42 : \text{weight} :: FA : FP$$

Therefore,

$$42 : \text{weight} :: 3\tfrac{1}{2} : 14$$

$$\text{Weight} = \frac{42 \times 14}{3\cdot5} = 168 \text{ lbs.}$$

EXAMPLE II.—In the above-given winch find what force two men would have to exert on the handles to heave up a weight of 200 lbs.

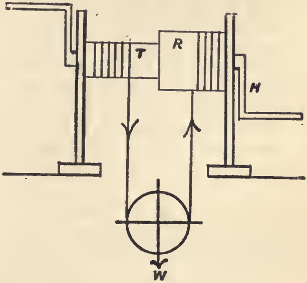
$$200 \times 3\cdot5 = \text{Power of 2 men} \times 14$$

Therefore,

$$\text{Power of each man} = \frac{200 \times 3\cdot5}{28} = 25 \text{ lbs.}$$

Chinese Windlass.—The Chinese windlass is a modification of the hand-winch; by having one-half of the barrel of a less diameter than the other (see Fig. 12) both ends of the whip are taken to the barrel opposite ways, while a single block hangs on the bight; as one end of the whip is wound round the large part of the barrel, the other part unwinds off the small part of the barrel, so that the distance the weight is lifted in one turn of the handles is equal to the difference between the circumferences of the two parts of the barrel; the purchase is therefore great, since it is so very slow. The strain on each part of the whip is equal to half the weight hanging on the block; therefore, since heaving round the handles unwinds half the weight from the small part of the barrel, the power applied to the handles is assisted by half the weight at the end of the radius of the small barrel. We therefore get the rule—

FIG. 12.



$$P \times H + \frac{W}{2} \times r = \frac{W}{2} R$$

P is the power,
H „ radius of handles,
R „ radius of large barrel,
W is the weight,
r „ radius of small barrel.

Therefore,

$$P \times H = \frac{W}{2} (R - r)$$

which may be stated as follows:

The weight raised by the Chinese windlass is equal to twice the product of the power into the radius of the handle divided by the difference of the radii of the two parts of the barrel.

EXAMPLE I.—The radii of the barrel are 3 inches and 5 inches; the radius of the handle is 14 inches; what weight will be raised by a power of 20 lbs. applied to one handle?

$$\text{Weight raised} = \frac{20 \times 14 \times 2}{2} = 280 \text{ lbs.}$$

EXAMPLE II.—A force of 15 lbs. is applied to each handle of a

Chinese windlass, the radius of the handle is 14 inches, the radii of the barrel are 4 and 6 inches; what weight will be raised?

$$\text{Weight raised} = \frac{2 \times 15 \times 14 \times 2}{2} = 420 \text{ lbs.}$$

When it is required to know the power which will raise a given weight we have the rule:—

The power is equal to the product of the weight into the difference of the radii of the barrel divided by twice the radius of the handles.

Example III.—What power will be required to raise 420 lbs., the radius of the handles being 14 inches and the radii of the barrel 4 and 6 inches?

The radii are 4 and 6, therefore $6 - 4 = 2$.

Radius of handle is 14 inches, therefore $2 \times 14 = 28$.

Hence—

$$\text{The power} = \frac{420 \times 2}{28} = 30 \text{ lbs.}$$

Example IV.—A weight of 560 lbs. has to be raised by means of a Chinese windlass; the handles are 14 inches radius, and the radii of the barrel are 3 and 6 inches. How many boys will be required on the handles when each boy exerts a force of 10 lbs.?

Here the difference of the radii is 3 inches.

Therefore,

$$\text{The power} = \frac{560 \times 3}{2 \times 14} = 60 \text{ lbs.}$$

Since each boy heaves with a force of 10 lbs., we get—

$$\text{Number of boys required} = \frac{60}{10} = 6.$$

There being but little gearing about this machine, the loss by friction is very small, therefore the practical efficiency will differ very little from the above theoretical efficiency.

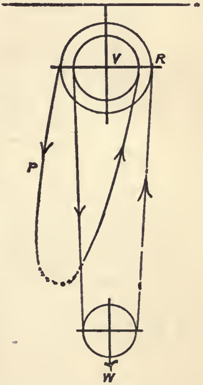
Spanish Windlass.—There is a form of the *wheel and axle* much used by sailors; as a temporary mechanical purchase it is second to none for its convenience and power. It can be rigged out of any round piece of wood or round bolt with another piece of wood, or iron, round or square for a heaver, and two pieces of rope or strops. It is much in request for many purposes aloft, such as setting-up top-gallant and topmast rigging, and dispenses with the service of four or five men waiting upon a tackle, for the one man may obtain a purchase on his windlass that will part the lanyards, and he gets a fairer lead between the lanyards and the shrouds than can ever be obtained by a tackle.

The heel of the jib-boom has always to be hove down to its place by a Spanish windlass, and it is sometimes used to trip a bower anchor when it is rigged between two boats, by laying a stout spar across their gunwales and heaving in between them.

Ship's Windlass.—The windlass for heaving up a ship's anchors is a form of the wheel and axle, but the power is applied in a more circuitous manner than in the single winch. The power is applied to long levers whose fulcrum is the pawl-bit; the resistance to these levers is communicated by long links attached to the ends of the pawl boxes, which are themselves short levers, and when turning the windlass form with the radius of the drum a continuous lever which is represented by the radius of the wheel on the axle. The windlass, therefore, consists of a drum or barrel and two levers acting at right angles to each other. In this kind of windlass the power cannot be increased in any way. Therefore since it is constant we need not trouble to calculate its purchase.

Weston's Differential Block is an application of the Chinese windlass. It consists of an iron gin, or block, having a double sheave in one piece, but the diameter of one part of the sheave is greater than the diameter of the other part; each part has a cogged score to grip the links of an endless chain, which is rove over the large sheave down through a single travelling gin, or block, and up over the small sheave; the ends are then joined by a connecting link (see Fig. 13). The power is applied to the chain on the large sheave, which, as it comes in to hand, is taken away by the small sheave. Therefore the distance through which a weight is raised in one turn of the sheave is equal to the difference between the circumferences of the two parts. The great convenience of Weston's differential block is that it will not overhaul itself when hanging a weight; it is therefore a very safe machine for placing or shifting heavy gear, such as a windlass, capstan, or winch, and would be very useful in the holds for properly stowing machinery.

FIG. 13.



Professor Jamieson, in his *Elementary Applied Mechanics*,* gives the cause of the load not overhauling the chain.

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* Published by Messrs. C. Griffin & Co., Ltd., Exeter Street, Strand.

In the first place, the scores of the sheaves are cogged, which prevents the chain from slipping round them. And the friction between the bush of the upper block and the pin is so great that more than 50 per cent. of the "work put in" is expended in overcoming it.

In all machines which require more than 50 per cent. of the applied force to overcome friction, this property of not overhauling themselves with a load holds good.

We will now give a rule for finding the theoretical efficiency of Weston's block, neglecting friction.

The power is equal to the product of the weight into the difference of the radii of the sheaves, divided by twice the radius of the large sheave.

Example I.—The radii of the sheaves in a Weston's differential block are 5 and 7 inches; required, the power to lift 1 ton.

Here $7 - 5 = 2$ the difference of the radii.

$$\text{Therefore the power} = \frac{20^{c} \times 2}{7 \times 2} = 2{\cdot}86 \text{ cwt.}$$

Example II.—Required the power to raise 3 tons with a Weston's differential block, the sheaves of which are respectively 7 and 8 inches radius.

Here the difference of radii is 1.

$$\text{Therefore the power} = \frac{60 \times 1}{8 \times 2} = \frac{60}{16} = 3\tfrac{3}{4} \text{ cwt.}$$

Example III.—A Weston's differential block has sheaves of $4\frac{1}{2}$ and 5 inches radii, what power will be required to lift 360 lbs.?

Here the difference of radii $= 5 - 4\frac{1}{2} = {\cdot}5$.

$$\text{Therefore the power} = \frac{360 \times {\cdot}5}{10} = 36 \times {\cdot}5 = 18 \text{ lbs.}$$

When we require to find what weight a given power will lift by Weston's block we have the rule—

The weight raised is equal to the product of the power into twice the radius of the large sheave, divided by the difference between the radii of the sheaves.

Example IV.—The radii of the sheaves of a Weston's block are $4\frac{1}{2}$ and 6 inches; what weight will be raised by a power of 84 lbs.?

$$\text{Weight raised} = \frac{84 \times 6 \times 2}{6 - 4{\cdot}5} = \frac{84 \times 12}{1{\cdot}5} = 672 \text{ lbs.}$$

Example V.—Required the weight which a power of $3\frac{3}{4}$ cwt. will raise with a Weston's block the sheaves of which have radii of 7 and 8 inches respectively.

Weight raised =

$$\frac{3{\cdot}75 \times 8 \times 2}{1} = \frac{3{\cdot}75 \times 16}{1} = 60 \text{ cwt.}$$

So far we have only dealt with the theoretical efficiency of Weston's differential block. From experiments made by Professor Jamieson with models, the actual working advantage obtained for this machine was only $31\frac{1}{4}$ per cent. of the work expended; but this low mechanical efficiency is fully compensated for by the great advantage it possesses of hanging a load without the necessity of belaying the fall, and the absence of all risk of the load coming down by the run.

Employing this practical efficiency of $31\frac{1}{4}$ per cent. in Example II., we get the co-efficient by which the weight to be lifted must be multiplied—

$$= \frac{100}{31{\cdot}25} = 3{\cdot}2$$

Therefore the practical power required to lift 3 tons is

$$= \frac{60 \times 3{\cdot}2 \times 1}{8 \times 2} = \frac{192}{16} = 12 \text{ cwt.}$$

If we work out the theoretical power and then multiply it by 3·2 we get the same result; for instance, in Example II., the theoretical power is 3·75 cwt.; therefore, $3{\cdot}75 \times 3{\cdot}2 = 12$ cwt.

Taking Example III., the theoretical power required to lift 360 lbs. is 18 lbs.; therefore, $18 \times 3{\cdot}2 = 57{\cdot}6$ lbs., the power required in practice.

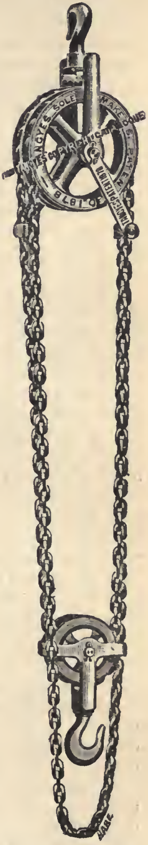
When we have given the power to find the weight it will lift practically, we get for the co-efficient of its practical efficiency

$$\frac{31{\cdot}25}{108} = {\cdot}3125$$

In Example IV. the power applied is 84 lbs., and the theoretical weight raised is 672 lbs. For the weight raised practically by a power of 84 lbs. we get—

$$\text{Weight raised} = \frac{84 \times 12 \times {\cdot}3125}{1{\cdot}5} = 210 \text{ lbs.}$$

FIG. 14



WESTON'S DIFFERENTIAL BLOCK.

When the weight is given, to find the power multiply it by 3·2 for the practical factor in the calculation. When the power is given, to find the weight it will lift multiply it by ·3125 for the practical factor in the calculation.

Since these values have been obtained from models only, it may be found that in actual practice the machine has a still lower efficiency than that allowed for by Professor Jamieson in his experiments.

The Capstan.—One of the machines most intimately associated with a ship is the capstan, and although rarely seen on the quarter-deck of a modern sailing-vessel, it still holds its place on the top-gallant forecastle, chiefly for the purpose of warping the ship about in port and in some ships for weighing the anchor. Its principal duty at sea is heaving down the fore tack.

The accompanying illustration (Fig. 15) gives the external view of a double-purchase ship's capstan. The head HD is detached from the drum B, but when it turns with the sun the drum moves with it in the same direction. When the head is turned against the sun it automatically throws itself into gear and becomes a double-purchase capstan without the necessity of any locking or unlocking by pins or bolts, while the drum still continues to move with the sun. Hence to convert the capstan from a single to a double purchase, the men at the bars have merely to turn round and walk against the sun.

The purchase of the capstan is calculated by the same rule as was applied to the wheel and axle. If we call the power applied by the men at the ends of the capstan bars P, and the weight or resistance they are heaving against W, R the length of the bar, r the radius of the drum, then $2P \times R = Wr$ when only two opposite bars are shipped and manned. If the whole 8 bars are manned we get $8PR = Wr$.

$$\text{Therefore, } W = \frac{8P \times R}{r}$$

Which may be stated in the following rule.

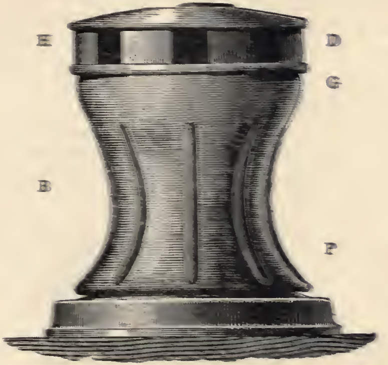
Multiply the power each man exerts on the bars by the number of men and by the length of the bar from the centre of the spindle; divide this product by the radius of the barrel increased by half the thickness of the rope; the result will be the resistance or weight.

When two or more men are heaving on each bar the point of application of their combined force must be considered to be situated half-way between them.

EXAMPLE I.—The barrel of a capstan has a radius of 9 inches;

8 bars are shipped, upon which 8 men are heaving each with a force of 40 lbs. at a point 7 feet from the centre of the spindle; the rope on the barrel is 2 inches in diameter. Calculate the weight they will heave on the rope.

FIG. 15.



PATENT AUTOMATIC SINGLE- AND DOUBLE-POWER WARPING CAPSTAN MADE BY HARFIELD & CO.

This capstan has been specially designed for simplicity and strength, and is particularly recommended for sailing-vessels.

The gearing is entirely self-acting, and so arranged that to work the capstan by single-power the men have to walk with the sun, while to work by double-power they have merely to walk against it, having no locking or connecting pins to adjust.

The spindle is of forged steel, and the pinions of the best crucible steel, and each part of the capstan is carefully made to withstand the strains as given below:

Capstan No.	1	to exert a pull of	16 tons	Tested to double these strains.
„	2	„	13 „	
„	3	„	9 „	
„	4	„	6 „	

INDEX TO THE ILLUSTRATION.

HD represents the capstan head.
B „ the barrel or drum.
G indicates the position of the gearing inside for doubling the purchase.
P „ the position of the pawls, also inside.

$$\text{Weight on rope} = \frac{8 \times 40 \times 84}{9 + 1} = 2688 \text{ lbs.} = 1{\cdot}2 \text{ tons.}$$

Example II.—In the same capstan what power must each man exert to put a strain of 2 tons on the rope when their force is applied at 8 feet from the axis of the capstan?

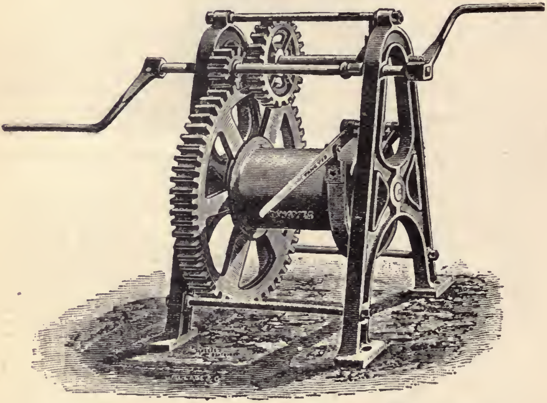
$$W \times (r + 1) = 8P \times R$$

$$\text{Therefore, } P = \frac{W \times (r + 1)}{8\,R}$$

$$\text{Force of each man} = \frac{2 \times 2240 \times 10}{8 \times 96} = 58{\cdot}3 \text{ lbs. nearly.}$$

Description of the Crab.—The crab on board ship is usually fitted to the gallows and fife-rail of the main-mast, and has a greater length of barrel than the iron-framed crab shown in the accompanying illustration (Fig. 16), and has in addition short end barrels on the single and double axles. The brake is fitted to a projecting rim on the cog-wheel of the main barrel so that the winch may be thrown completely out of gear when lowering a weight, thereby avoiding the jarring on the cogs attendant upon

Fig. 16.



Double Crab with Lever Brake. Manufactured by Tangyes, Limited.

letting the weight go by the run when loading boats or lighters tumbling about alongside. The ship's crab is always fitted with the double purchase, but for ordinary work the single purchase only is used; and, instead of using the iron brake for lowering, a stout piece of flat sinnet is taken round the end of the main barrel with two or more turns, according to the weight on the winch.

The illustration gives a photographic perspective view of a portable double crab, such as is sometimes used on board when rigging the ship or working heavy cargo from other than the main hatch. The gearing is similar to that of the ship's crab, excepting that the brake is fitted to the end of the barrel. An examination of the figure will show how, by sliding the pinions along the shaft, the winch may be thrown into or out of double or single gear. Since the double crab may be used as a single purchase crab, the latter is rarely seen on a ship, except for some exclusively special duty; such as reeling up steel-wire hawsers, and heaving in the log-line in fast mail steamers.

The *crab* winch is a combination of the *wheel and axle,* where the power is communicated by means of cogged wheels and is applied as in the hand winch, to the handles which turn a spindle, upon which is fixed a pinion whose cogs turn a large cog-wheel fixed to another spindle, at the other end of which is fixed a pinion whose cogs turn another large cog-wheel fixed to the barrel of the winch. To find the purchase of a *crab* we have the following rule, which is general for any train of wheels, however numerous.

RULE.—*As the power is to the weight lifted, so is the product of the radii of all the pinions to the product of the radii of all the wheels.*

Or since the number of cogs in the pinions and wheels are as the radii. *The power is to the weight lifted as the product of the radius of the barrel and the number of cogs in all the pinions, is to the product of the radius of the handle and the number of cogs in all the wheels.*

EXAMPLE I.—A crab winch has the following dimensions:—

Radius of handle	14 inches.	Radius of barrel	4 inches.
1st large wheel	36 cogs.	1st pinion	12 cogs.
2nd "	72 "	2nd "	12 "

Thickness of the rope, 1 inch, which gives radius of barrel $4\frac{1}{2}$.

Therefore, power : weight $:: 4{\cdot}5 \times 12 \times 12 : 14 \times 36 \times 72$

$:: \quad 648 \quad\quad 36288$

$$\frac{\text{Weight}}{\text{Power}} = \frac{36288}{648} = 56.$$

That is, the purchase of such a winch is 56 times the power applied; this is the theoretical purchase, but in practice 40 per cent. is usually allowed for friction—

Hence 100 : 100–40 :: 56 : practical effective purchase.

$$\text{Effective purchase} = \frac{60 \times 56}{100} = 33{\cdot}6.$$

Note.— $\frac{60}{100} = 0{\cdot}6$ a constant multiplier to the theoretical purchase.

This is a constant quantity for this particular crab; hence, if the power is given, the weight it will lift is found by multiplying the power by 33·6; or, if the weight is given, the power is found by dividing the weight by 33·6.

Suppose a weight of 3 tons is to be hove up, required the effective power on the handles.

$$\text{Power} = \frac{60^{c} \times 112}{33{\cdot}6} = 200 \text{ lbs.}$$

Now suppose each man heaves with a constant force of 21 lbs., we get the number of men required to heave up 3 tons

$$= \frac{200}{21} = 9\tfrac{11}{21} \text{ or } 10 \text{ men.}$$

EXAMPLE II.—A crab has the following dimensions:

Radius of handle	14 inches.	Barrel radius	4 inches.
1st cog wheel	54 cogs.	1st pinion	9 cogs.
2nd "	54 "	2nd "	9 "

Required the purchase of the winch, allowing 1 inch for rope.

$$\begin{array}{lrcrcrcr} \text{Wheels} & 14 & \times & 54 & \times & 54 & = & 40824 \\ \text{Pinions} & 5 & \times & 9 & \times & 9 & = & 401 \end{array}$$

$$\text{Theoretical purchase} = \frac{40824}{401} = 101{\cdot}8$$

The effective purchase $= 101{\cdot}8 \times 0{\cdot}6 = 61{\cdot}1$.

Four men are heaving on the handles with a constant force of 22 lbs.; what weight will they raise?

$$\text{Power} = 4 \times 22 = 88.$$

$$\text{Weight raised} = 88 \times 61{\cdot}1 = 5376{\cdot}8 \text{ lbs.} =$$

2 tons 8 cwt. 0 qr. 3 lbs.

EXAMPLE III.—A crab of the following dimensions is given.

Radius of handle	14 inches.	Radius of barrel 3 inches (allowing 1 in. for thickness of rope).	
1st wheel	54 cogs.	1st pinion	9 cogs.
2nd "	90 "	2nd "	9 "

$$\text{Wheels } 14 \times 54 \times 90 = 68040.$$
$$\text{Pinions } 4 \times 9 \times 9 = 324.$$

This gives a purchase $= \frac{68040}{324} = 210.$

Multiplying 210 by the constant 0·6 gives the effective purchase—

$$= 210 \times 0{\cdot}6 = 126.$$

How many men heaving with a force of 20 lbs. each on the handles will be required to raise a weight of 4 tons?

$$\text{Power} = \frac{4 \times 20 \times 112}{126} = 71\tfrac{1}{2} \text{ lbs. nearly.}$$

$$\text{Number of men} = \frac{71\frac{1}{2}}{20} = 3\tfrac{1}{2} \text{ nearly.}$$

Example IV.—In a geared capstan there are 60 cogs on the inside of the drum which has its motion communicated to it by the pinion fixed on the spindle, which carries the crown and bars; this pinion has 12 cogs; between it and the drum are three cog-wheels running freely on their axes, but merely for communication between the drum and pinion; hence they contribute nothing to the purchase of the machine. The bars are 8 feet in length and the power is applied at 7 feet from the axis.

Find the purchase of such a capstan to radius 4 inches? This we do in the same manner as for the winch.

Length of bar 7 feet. Radius of drum 11 inches; allow 1 inch for thickness of rope.

Drum wheel 60 cogs. Pinion 12 cogs.

Therefore, $P : W :: 1 \times 12 : 7 \times 60.$

$$\frac{W}{P} = \frac{7 \times 60}{12} = \frac{420}{12} = 35.$$

That is, the purchase is theoretically 35 times the power; allowing 40 per cent. for friction, we multiply this by the constant 0·6, which gives the effective purchase—

$$35 \times 0{\cdot}6 = 21 \text{ a constant.}$$

Six men are heaving with a force of 40 lbs. each, what weight will they raise?

Weight $= 40 \times 6 \times 21 = 5040$ lbs. $=$ 2 tons 5 cwt.

Examples on the Crab Winch.

A single crab has a barrel 7 inches in diameter; the large wheel has 72 teeth, the pinion 9 teeth and the radius of the handle is 14 inches; the diameter of the rope working on the barrel is 1 inch. Calculate the weight which two men exerting a force of 20 lbs. each on the handles will raise, neglecting friction. *Ans.* 1120 lbs.

In the above example find the weight which would be lifted when an allowance of 40 per cent. is made for loss by friction. *Ans.* 672 lbs.

A double crab has a barrel of 4 inches radius, the large wheel has 96 teeth, the small wheel 24 teeth, and the pinions have each 12 teeth; the radius of the handles is 14 inches. Calculate the weight which four men will lift when they exert a force of 22 lbs. each on the handles, allowing a loss of 40 per cent. for friction, and increasing the radius of the barrel by 1 inch for the rope used. *Ans.* 2364·44 lbs., or 1·056 tons.

A double crab has a barrel of 6 inches diameter, there are 96 teeth in the large wheel, 36 teeth in the small wheel, and 12 teeth in each of the pinions; the handles are 14 inches radius. Allowing 40 per cent. for loss by friction, what power will have to be applied to the handles to lift 2 tons, when the radius of the rope is 1 inch? *Ans.* 85·4 lbs.

A geared capstan has 16 teeth in the pinion which is fixed on the spindle; in the bottom rim of the drum or body of the capstan there are 48 teeth; the diameter of the drum or barrel is 18 inches; the power is applied on the bars at a point 5 feet from the centre of the spindle; the diameter of the rope is 2 inches. What purchase will 6 men heaving with a force of 40 lbs. each on the bars effect on the rope, allowing 40 per cent. for friction? *Ans.* 2592 lbs. = 1·15 tons.

The diameter of a windlass barrel is 2 feet, the length of the pawl box is 1 foot; the levers are 8 feet in length from the axis on the pawl bit, and the link which works the pawl box is 1 foot from this axis; the radius of the barrel must be increased by 2 inches for the cable. Allowing 40 per cent. for friction in the machine, calculate the purchase obtained on the cable by 16 men exerting an average force of 40 lbs. each on the levers. *Ans.* 3·45 tons.

CHAPTER V.

TACKLES.

Tackles and their Theoretical Power.—In any kind of tackle the power applied to the fall multiplied by the number of parts at the travelling block gives the purchase, or the power multiplied by twice the number of sheaves in the travelling block gives the same result if the standing part is fast to fixed block.

Hence in a single *whip* the power balances the weight, therefore a single block gives no purchase, but merely changes the direction of the power.

In a *whip* and *runner* the purchase is twice the power.

In the *gun-tackle* there are two parts of the fall at one block and three at the other, hence its purchase will be twice the power when the block with two parts is made the travelling block, and three times the power when the travelling block is the one hauled upon.

The *luff-tackle,* which consists of a double and single block, has three parts at the single block and four parts at the double block; hence, with the single block travelling, the purchase is three times the power, and with the double block travelling, four times the power.

A *tackle rove* with two double blocks has four parts at one block and five at the other; hence the purchase is four and five times the power, according to the block which is travelling.

The *jeer* or *purchase tackle,* which has three sheaves in each block, has six parts at one block and seven at the other. Therefore the purchase of this tackle is six times and seven times the power, according to which is made the travelling block.

The *single burton* consists of a fixed single block through which is rove one end of a fall; this end is spliced or seized round another single block which travels; through this travelling block is rove the other end of the fall, while into the bight between the fixed and travelling blocks is seized a hook. At the travelling block are three parts of the fall; therefore the purchase is three times the power. Although the purchase is the same as that of the luff-tackle, yet it has the advantage over the latter of being easily and quickly rounded in and overhauled; hence it is largely used in working cargo, but it requires a long drift for a short hoist.

Combination of Tackles.—Many combinations of these purchases may be made, such as a luff upon a runner used in setting up rigging; it doubles the power of the luff. A runner upon a luff, when the double block is the traveller, gives a purchase of eight times the power; whereas with the single block travelling the purchase would only be six times the power. A general rule for finding the purchase of any combination of tackles is: *multiply the purchase of the main tackle by the purchase of the tackle applied to its hauling part.*

Practical Efficiency of Tackles.—The practical efficiency of tackles differs from the above-given theoretical purchase owing to the stiffness of the rope, and the friction of the sheaves and pins of the blocks; it also depends on the size of the rope in relation to the *swallow* of the blocks and the diameter of the sheaves; therefore, the fall should run in the score of the sheaves free from the shell of the block and the diameter of the sheaves can never be too great for the efficient working of, and fair play to, the rope, especially if it is at all stiff.

Some practical men increase the weight to be lifted by 12 per cent. of itself for every sheave in the purchase; this may be considered in practice as $\frac{1}{8}$ of the weight for every sheave; hence, to calculate the effective purchase of a tackle, the following is the rule:—

RULE:—*Multiply $\frac{1}{8}$ of the weight to be lifted by the number of sheaves in use, add this product to the weight itself and divide the sum by the theoretical purchase, the result will be the practical power to be applied to the fall.*

Examples.—EXAMPLE I.—What power will be required to lift 8 tons with two treble blocks, the hauling part of the fall leading direct from the upper block?

Here we have 6 sheaves, for each of which must be added to the weight, 8 tons, $\frac{1}{8}$ of itself; therefore, since $\frac{1}{8}$ of 8 tons = 1 ton, and there are 6 sheaves,

$$8 + 6 = 14 \text{ tons} = \text{the resistance.}$$

Divide by the theoretical purchase, 6; therefore,

$$\frac{14}{6} = 2\tfrac{1}{3} \text{ tons} = \text{the power to be applied to the fall.}$$

EXAMPLE II.—A purchase consists of two treble blocks, and the fall leads through a block on deck. What power will be required to lift 16 tons?

In this system there are 7 sheaves:—

Therefore, $16 + \frac{7}{8}$ of $16 = 16 + 14 = 30$ tons, the practical resistance.

The theoretical purchase is 6. Therefore,

$$\frac{30}{6} = 5 \text{ tons} = \text{the power required.}$$

Example III.—A purchase consists of two treble blocks, and the standing part of the fall is made fast to the travelling block, while the running part leads down through a block at the mast head. What power will be required to lift 16 tons?

In this case there are 7 parts at the travelling block, therefore, by the rule, the theoretical purchase is 7; there are also 7 sheaves in use, therefore the resistance is:—

$$16 + \tfrac{7}{8} \text{ of } 16 = 16 + 14 = 30 \text{ tons.}$$

Divide by the theoretical purchase, therefore,

$$\frac{30}{7} = 4\tfrac{2}{7} \text{ tons} = \text{the power required.}$$

Example IV.—A purchase of two treble blocks has the standing part fast to the travelling block, and the fall leads direct to the winch. What power will be required to lift 20 tons?

Since the standing part is fast to the travelling block, the fall leads from it direct to the winch; hence there are 6 sheaves in use, and the theoretical purchase is 7; therefore,

$$20 + \tfrac{6}{8} \text{ of } 20 = 20 + 15 = 35 \text{ tons resistance.}$$

Therefore the power required is:—

$$\frac{35}{7} = 5 \text{ tons.}$$

To find the Resistance a given Power will overcome with a given Tackle.—When the power of a winch or capstan is known, it may be required to find out what weight it will lift with a given purchase, allowing for friction by using the same factor as was employed in the direct problem of the efficiency of tackles.

Rule:—*Multiply the power of the winch by 8 times the theoretical purchase and divide by the sum of the number of sheaves added to 8.*

Example V.—The power of a winch is $2\frac{1}{3}$ tons; what weight will it lift with a purchase of two treble blocks, the theoretical purchase being 6, and six sheaves being in use?

Multiply the power by 8 times the theoretical purchase,

$$= 2\tfrac{1}{3} \times 48 = 112;$$

Divide this by the number of sheaves, 6, added to 8 = 14.

Therefore, $\frac{112}{14} = 8$ tons,

the weight the winch will lift.

Example VI.—The power applied to the fall of a tackle is 5 tons; what weight will it lift when the number of sheaves in use is 7 and the theoretical purchase is 6?

$$\text{Weight it will lift} = \frac{5 \times 6 \times 8}{8 + 7} = \frac{240}{15} = 16 \text{ tons.}$$

Example VII.—A power of $4\frac{2}{7}$ tons is applied to the fall of a tackle having 7 parts at the travelling block and 7 sheaves in use. Required the weight this power will lift.

Here we have a theoretical purchase of 7, and 7 sheaves in use.

$$\text{The weight it will lift} = \frac{4\frac{2}{7} \times 8 \times 7}{7 + 8} = \frac{240}{15} = 16 \text{ tons.}$$

It will be seen that these inverse examples are merely the three first direct problems reversed. The examples have all been given for heavy lifts, since it is only for such that the necessary precaution of making exact calculations must be attended to, if assurance against risk of accident is desired.

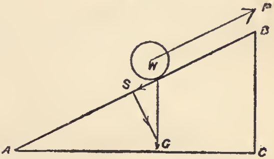
Mechanical Advantage of the Old Man.—The *Old Man* is a heavy gin having a frame and sheave of large swallow, sufficient to take the ship's chain cable, and used for the purpose of taking the cables on board and stowing them in the chain lockers; it is also used when cables are being taken on board as cargo. The manner of using it is to lash it aloft to the foremost swifter of the rigging at a convenient height above the deck, or it may be hooked to the head of a derrick, whichever makes the most direct lead to the place where the cable is to be stowed. A stout rope is rove through the *Old Man* and bent to the right end of the cable—*i.e.*, to the end which brings the pins of the shackles uppermost; the rope is now taken to the winch and the cable is hove through the *Old Man* till it reaches the winch, when a fleet of the rope is made, and the end of the cable paid down into the locker until it reaches the bottom; when this has been done the winch is no longer required, for the cable hanging with equal parts over the side and down the locker is balanced, and has only to be hauled upon with a force sufficient to overcome the friction of the *Old Man* to get the whole cable on board. At the beginning of the operation the length of cable on board is greater than that over the side, but as it rises in the locker it becomes less, and requires, in addition to the force to overcome friction, a pull equal to the difference in the weight of the two legs. Indeed, all considerable lengths of chain which must be brought on board on end should be taken in in this manner, as it saves labour, avoids noise, and does not mark the waterways decks or hatch-combings.

CHAPTER VI.

THE INCLINED PLANE.

The Inclined Plane and its Practical Application.—The *inclined plane* is a plane which makes an angle with the horizon, such as a skid or plank for rolling casks up or down, or for moving heavy weights upon from a lower to a higher level and *vice versa*.

FIG. 17



In Fig. 17 AB is the inclined plane and BC its height, AC its horizontal length, and AB its slant length; W is a weight being rolled up the plane. From W draw WG, containing as many units of length as there are units of weight in W; from G draw GS perpendicular to the face of the plane AB; then GS represents the pressure of the body W on the plane and SW the force with which it tends to roll down the plane, equal and opposite to the power WP which retains it in position.

In the triangle WGS the angle GSW is a right angle and the side WG is parallel to BC, therefore the angle SWG is equal to the angle ABC and the angle SGW is equal to the angle BAC, therefore the triangle WGS is similar to the triangle ABC and the sides about the equal angles of the two triangles are proportional; therefore

$$WS : WG :: BC : AB.$$

The power of the inclined plane as a mechanical agent is given in the following rule:

RULE.—*As the power is to the weight so is the height of the plane to its slant leugth.*

$$P : W :: BC : AB$$

Therefore, the power $P = \text{weight } W \times \frac{BC}{AB}$ —

Any three of these quantities being given, the fourth can always be found, since BC represents the power required to prevent the weight W from rolling down the plane, and AC represents the pressure which the weight W exerts perpendicular to the surface of the plane. In practice the power is usually applied parallel to the surface of the plane, as this direction gives the greatest purchase; when a parbuckle is used the purchase is doubled.

For solving questions such as the above the traverse table may be advantageously used for approximate results.

Rule.—*To find the power enter the table with the slant length as a distance, the height of the plane in a departure column, and under the course which these give find the weight in a distance column; and the departure will be the power required; and the diff. lat. will be the pressure on the plane.*

Example I.—A skid is 18 feet in length, and one end is raised 6 feet; required the power applied parallel to the plane to raise 4 cwt., neglecting friction.

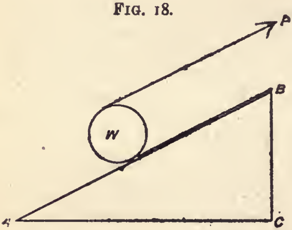
$$P : 4 \text{ cwt.} :: 6 : 18$$

Therefore $$P = \frac{4 \times 6}{18} = \frac{24}{18} = 1\tfrac{1}{3} \text{ cwt.}$$

By the traverse table 18 as a distance and 5·9 the nearest to 6 in a departure column give the angle 19°; under this course with the weight 4 cwt. in a distance column is found in a departure column $1{\cdot}3 = P = 1\frac{1}{3}$ cwt.

If the weight to be raised had been a cask or a cylinder, so that it might be rolled up the plane, then the power would be reduced to one-half, or 75 lbs., since rolling the body up the plane would be practically the same as applying a parbuckle, only in the former the rolling power would be applied by pushing from below, while in the latter the power would be applied by hauling from above. In the figure, AB is the inclined plane, BC its height, W is the weight to be rolled up by means of the parbuckle, which consists of a line made fast at B, passing under the cask W and brought over the top to the point P where the power is applied parallel to AB,

Fig. 18.



by which means the purchase is doubled or the power required is reduced to one-half.

EXAMPLE II.—A cask weighing 10 cwt. has to be rolled up a skid 20 feet in length and 4 feet in height by means of a parbuckle; required the power to roll it np.

$$\text{Power} : 10 \text{ cwt.} :: 4 : 20$$

Therefore

$$\text{Power} = \frac{10 \times 4}{20} = 2 \text{ cwt.}$$

Therefore

$$\text{Power on parbuckle} = 1 \text{ cwt.}$$

EXAMPLE III.—An iron mill roller weighing $2\frac{1}{2}$ tons has to be lowered down an inclined plane, which has a descent of 1 foot in 6, what will be the strain on the running part of the parbuckle when lowering?

Here the weight of the plane is to its slant length as 1 is to 6; therefore

$$\text{Power} : 50 \text{ cwt.} :: 1 : 6$$

Therefore

$$\text{Power} = \frac{50}{6} = 8\tfrac{1}{3} \text{ cwt.}$$

But the strain on the parbuckle is only a half of this,

$$= 4\tfrac{1}{6} \text{ cwt.}$$

The inclined plane is extensively used for stacking minerals by means of stout planks rising from the ground to the top of the stack in a series of ziz-zag paths, over which the mineral is carted in wheelbarrows.

A ship's slipway is an application of the inclined plane fitted in a special manner with rails, upon which run the small, but massive, wheels of the carriage. Down the centre of the slipway runs a strong iron ratchet-plate which takes the heavy pawls of the carriage to prevent it slipping back, while the hauling chain is being shortened link by link, as these links usually consist of large iron bars, which are removed one by one as they reach the hauling engines.

A ship's slipway has a rise of 17·4 feet for every 100 feet of length of the slip. The total weight of the carriage with a ship upon it is 1000 tons, what will be the force necessary to haul the ship up, neglecting the resistance of friction?

Here we have the height of the inclined plane per 100 feet and the weight to be hauled up. Therefore—

Length of slip : height of slip :: 1000 tons : hauling force
100 : 17·4 :: 1000 : hauling force.

$$\text{Hauling force} = \frac{17{\cdot}4 \times 1000}{100} = 174 \text{ tons.}$$

This is the force which would keep the ship from sliding down the slipway, and is equal to the strain upon the hauling chain. But the traction must be added to 174 tons to get the strain on the chain when the ship is being hauled high and dry. Let us take the traction force equal to 15 lbs. per ton.

Therefore, traction $= 15 \times 1000 = 15000$ lbs.

Traction in tons $= \frac{15000}{2240} = 6{\cdot}7$ tons.

Hence, strain on chain $= 174 + 6{\cdot}7 = 180{\cdot}7$ tons.

The Wedge.—The wedge may be conceived as consisting of two inclined planes placed back to back. *Therefore the power is to the resistance as half the thickness of the back is to the length.* Owing to the great friction of the wedge and the fact that the power has to be applied by blows from a hammer or maul it is difficult to calculate its purchase in actual practice. It is, however, evident that the thinner the wedge the greater is its power, which may yet be increased by driving wedges from opposite directions.

The uses of the wedge on board ship are very numerous. The hatches have their tarpaulins secured by wedges, which are much more effective in keeping hatches water-tight than the new-fashioned screw through the cleet, which presses the batten at a mere point, with the effect of causing the batten to bulge away from the hatch combing between the cleets, unless the battens are thicker than those usually used. Wedges are also useful for tightening the lashings on a *fished* spar, for wedging a slack cap, for jamming the lanyards in the lower dead eyes to prevent them chafing in bad weather when the lee rigging slackens as the vessel lurches; they are also useful for raising any heavy weight through a small distance, for the purpose of lashing or slinging it. Ships themselves are often raised by means of thin wedges driven under the *bilge-ways* on both sides simultaneously to enable the keel blocks to be removed.

The Screw—Great Power of the Screw.—The screw may be considered as an inclined plane wrapped round a cylinder, and its application is that of the movable inclined plane, where the power is applied parallel to the horizontal base of the plane instead of parallel to the inclined surface of the plane, as in the preceding examples.

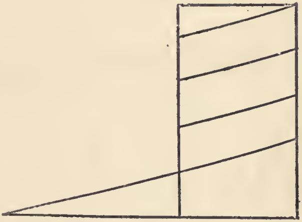
The spiral length of the thread in one turn of the screw is the length of the inclined plane, and the *pitch* or distance measured from the top of one thread to the top of the next one above it is the height of the plane. Owing to the smallness of the interval between the threads the screw is a very powerful machine, but the factor of friction is very great, and amounts to as much as 60 per cent. of the work put into the machine, whereby its efficiency is reduced to 40 per cent. of its theoretical power.

Rule for the theoretical power of the screw:—

As the pitch or interval between the threads is to the length of a turn of the screw, so is the power to the weight lifted or pressure exerted.

As the screw is usually worked with a bar or lever, *the circumference of the circle described by the point on the bar at which the power is applied is to the pitch as the weight lifted is to the power.*

FIG. 19.



EXAMPLE I.—A screw has a thread $\frac{3}{8}$ inch pitch, and it is worked by a bar to which is applied a power of 32 lbs. at two feet from the axis of the screw, required the resistance the screw will overcome, (1) theoretically, (2) practically.

The circumference of a circle equals the radius × 2π where $\pi = 3{\cdot}1416$, therefore—

Circumference $= 24 \times 2 \times 3{\cdot}1416 = 150{\cdot}8$ inches.

Hence, 32 lbs. : Resistance :: $\frac{3}{8}$ inch : 150·8.

$$\text{Resistance} = \frac{150{\cdot}8 \times 32}{\frac{3}{8}} = \frac{150{\cdot}8 \times 32 \times 8}{3} = \frac{38604{\cdot}8.}{3}$$

$= 12868{\cdot}3$ lbs. $= 5{\cdot}75$ tons = theoretical resistance.

Now the practical efficiency of the screw is only 40 per cent. of this, therefore the factor for friction is ·4.

Hence, $5{\cdot}75 \times {\cdot}4 = 2{\cdot}3$ tons = effective resistance.

EXAMPLE II.—The interval between the threads of a screw is $\frac{1}{2}$ inch, what pressure will the power of a man heaving with a force of 120 lbs. at a point on the lever 3 feet from the axis of the screw exert with the screw, allowance being made for the friction?

Circumference of circle $= 36 \times 2 \times 3{\cdot}1416 = 226{\cdot}2$ inches.

∴ ·4 × 120 lbs. : pressure :: $\frac{1}{2}$ inch : 226·2 inches.

$$\text{Resistance} = \frac{48 \times 226{\cdot}2}{\frac{1}{2}} = 10857{\cdot}6 \times 2 = 21715{\cdot}2 \text{ lbs.}$$

$= 9{\cdot}69$ tons.

Improvised Screw.—The ingenious contrivance which sailors employ for drawing a bolt or treenail out of a ship's hull, or out of any mass of wood, is an improvised screw, and is known by the name of a Spanish windlass. It consists of several turns of a rope taken round the bolt, and by means of a *heaver* or handspike through a timber or marlin-spike hitch, turning the bolt in its seat, whereby the other part of the rope, which is kept pretty taut, works in between the wood and the turns already on the bolt, and performs the part of a screw, simple and rude in construction, but extremely powerful, and capable of drawing the stem bolts of a ship (which are the longest bolts in her hull), provided they remain straight within the mass of the stem pieces. In such an improvised mechanical power it is unnecessary to attempt calculation, since it is merely a make-shift in the absence of other mechanical means. As in the legitimate metal screw, its elementary principle is the inclined plane.

The uses to which this form of Spanish windlass may be put on board ship are numerous. By its means, pumps may be drawn when they happen to get choked, davits raised from their sockets, capstan spindles drawn from their settings, and eye or other bolts removed from damaged or broken spars and ship's furniture.

CHAPTER VII.

THE CENTRE OF GRAVITY.

Centre of Gravity of Bodies and Systems of Bodies.—The *centre of gravity* of a body, or of a system of bodies, is that point on which the body or system will balance itself in any position whatever; or it is that point which, being supported, the body or system of bodies will also be wholly supported; therefore the whole weight of a body may be considered as collected at its *centre of gravity.*

The centre of gravity of a body is not always situated within the substance of the body. For instance, the centre of gravity of a hoop is not in the hoop at all, but in the centre of the circle it describes; nor is the centre of gravity of an empty ship within the substance of the ship, but is situated somewhere in the empty hold.

To find the centre of gravity of a body experimentally, suspend the body by a string and hang a plumb-line to the same point. Mark the plumb-line on the body, again suspend the body by some other point as nearly at right angles to the former point as practicable, and the point where the plumb-line intersects the former line is the centre of gravity.

If a body be at rest upon a horizontal or inclined plane, and if a line drawn perpendicular to its centre of gravity hangs within its base or points of support, the body will remain at rest; but if the perpendicular line hangs without the points of support or base, the body will fall or roll. Hence the reason that sailors have their *chests* made with *tumble-home* sides to diminish their tendency to capsize. The leaning tower of Pisa is an instance of a structure remaining stable as long as the perpendicular from the centre of gravity of the tower continues within the base of the building; otherwise the strain of supporting it would be thrown upon the cohesion of the materials at the base.

Centre of Gravity of Certain Bodies. *To find the centre of gravity of certain bodies geometrically.*—The centre of gravity of a material straight line of uniform thickness and density is in the middle of the line.

To find the centre of gravity of a triangle.—Bisect any two of the sides, and from these points of bisection draw lines to the angles opposite to them; the intersection of these lines will be the centre of gravity when the triangle is of uniform thickness and density.

The centre of gravity of a parallelogram is found at the intersection of the diagonal lines drawn through the opposite angles.

Centre of Effort of Sails.—To find the centre of gravity, or (as it is called when applied to areal forces) the *centre of effort* of a jib, proceed as for finding the centre of gravity of a triangle.

To find the centre of effort of a square sail, such as a topsail, draw a plan of the sail, find the middle of the head and the foot, and join these points by a straight line; next draw a diagonal line from port earing to starboard clew, this divides the sail into two unequal triangles; find the middle points on the leaches. Call the smaller triangle *a* and the large one *b*. Find the centre of effort of *a* by drawing a line from the middle of the starboard leach to the port earing, and another line from the middle of the head to the starboard clew; their intersection is the centre of effort of triangle *a*. For triangle *b*, from the middle of the port leach draw a line to the starboard clew, and another line from the middle of the foot to the port earing; their point of intersection is the centre of effort of triangle *b*. Join these centres of effort by a straight line, and the point where this line cuts the middle line joining the head and foot is the centre of effort for the whole sail.

To find the centre of effort of a spanker or trysail.—Upon a plan of the sail draw a diagonal line from throat to clew, find the centres of effort of these two triangles, and join them by a straight line. Next draw a diagonal line from tack to head cringle, and find the centres of effort of these two triangles; join them by a straight line; where this cuts the former line will be the centre of effort.

Centre of Gravity of Plane and Solid Bodies.—*To find the height of the centre of gravity of a semicircle above the base, multiply the diameter of the semicircle by* 4 *and divide by* 3π, *or multiply the diameter by* 0·4244.

The height of the centre of gravity of a *parabola* is $\frac{2}{5}$ of its vertical height from the base.

In a *cone* or *pyramid* the centre of gravity is $\frac{1}{4}$ of the vertical axis from the base.

In a *paraboloid* the height of the centre of gravity from the base is $\frac{1}{3}$ the vertical axis.

In a *hemisphere* the centre of gravity is $\frac{3}{8}$ of the radius from the base.

In a *prism* or *cylinder* the centre of gravity is at the middle of the vertical axis.

It will be apparent that when all the bodies having the above figures are hollow, the centre of gravity will not be within the substance of the bodies, but in the hollow space enclosed by these figures.

When a body is supported by its centre of gravity, it will remain at rest in any position whatsoever, but its position will change with every slight disturbance; hence, to secure for it stability of position, its centre of gravity must be below its point of support; as, for example, in the compass-card in both dry and liquid compasses.

Centre of Gravity of a System of Bodies.—*To find the centre of gravity of two bodies or weights, joined by a rigid bar, which is considered to be without weight.*

RULE.—*As the sum of the weights is to the distance between them, so is the greater weight to the distance of the lesser weight from the centre of gravity.*

Examples. EXAMPLE I.—Two weights of 10 lbs. and 6 lbs. are joined by an inflexible rod, without weight and 6 inches in length; find their centre of gravity.

10 + 6 : 6 :: 10 : dist. of centre of gravity from 6 lbs.

Centre of gravity from the 6 lbs. $= \dfrac{6 \times 10}{16} = 3\tfrac{3}{4}$ inches.

This gives the centre of gravity $2\tfrac{1}{4}$ inches from the 10 lb. weight.

This may be proved by the equality of *moments* round the centre of gravity $\quad 10 \times 2\tfrac{1}{4} = 6 \times 3\tfrac{3}{4}$

EXAMPLE II.—A beam is 40 feet in length, of uniform thickness and density, and supports the following weights: 1 ton at 16 feet from the end A; 3 tons at 5 feet from the same end; 8 tons at 9 feet from the end B; while the beam itself weighs $2\tfrac{1}{2}$ tons and is supported at both ends; find the centre of gravity of the whole system.

RULE.—*Multiply each weight into its distance from the point* A, *and divide the sum of the products by the sum of the weights; the quotient will be the distance of the centre of gravity from* A.

$$\begin{array}{rcrcrcll}
16 & \times & 1 & = & 16 & = & \text{moment of} & 1 \text{ ton} \\
5 & \times & 3 & = & 15 & & \quad ,, & 3 \text{ tons} \\
31 & \times & 8 & = & 248 & & \quad ,, & 8 \;\; ,, \\
20 & \times & 2{\cdot}5 & = & 50 & & \quad ,, & 2{\cdot}5 \text{ weight of beam.} \\
\hline
 & & 14{\cdot}5 & & 329 & & &
\end{array}$$

$\dfrac{329}{14{\cdot}5} = 22{\cdot}6$ feet distance of centre of gravity from A.

Centre of Gravity of Ships and Cargo. Example III.—The centre of gravity of 1000 tons of cargo in a ship's lower hold is 8 feet above the top of the keel; 900 tons in the 'tween decks, centre of gravity 19 feet above the keel; and the centre of gravity of the ship's hull, which weighs 2000 tons, is 14 feet above the keel. Find the height of the centre of gravity of the whole ship and cargo.

Lower hold 8 × 1000 = 8000
'Tween decks 19 × 900 = 17,100
Ship ... 14 × 2000 = 28,000

Total weight = 3900 53,100 = sum of moments.

Height of centre of gravity $= \frac{53,100}{3900} = 13 \cdot 6$ ft. above the keel.

Change of Centre of Gravity caused by Filling the Ballast Tanks. Example IV.—The centre of gravity of a vessel with clean swept holds is 12 feet above the keel, with the ballast tanks empty; the weight of the ship is 2000 tons. How much will the centre of gravity be lowered by filling the ballast tanks, which contain 600 tons, the centre of gravity of which is $2\frac{1}{2}$ feet above the keel?

Ship . . 12 × 2000 = 24,000
Ballast . . 2·5 × 600 = 1500
Sum of weights = 2600 25,500 = sum of moments.

Height of centre of gravity $= \frac{25,500}{2600} = 9 \cdot 84$ feet.

Therefore centre of gravity lowered $= 12 - 9 \cdot 84 = 2 \cdot 16$ feet.

Change due to Emptying Ballast Tanks. Example V.—The total weight of ship and cargo, with the ballast tanks full, is 4000 tons; the centre of gravity is 14 feet above the keel. The centre of gravity of 600 tons of ballast is 2 feet above the keel. How much will the centre of gravity be raised by emptying the ballast tanks?

Here we proceed, as in the former examples, to find the *moments* of the weights with respect to the keel, but the weight to be removed must be subtracted from the total weight, and its *moment* subtracted from the *moment* of the total for the new *moment* and its divisor.

Total weight 14 × 4000 = 56,000 = moment.
Ballast 2 × 600 = 1,200 „

Diff. weights = 3400 54,800 = diff. moments.

$$\text{New centre of gravity} = \frac{54800}{3400} = 16{\cdot}11 \text{ feet.}$$

Therefore, centre of gravity raised $16{\cdot}11 - 14 = 2{\cdot}11$ feet.

To find the distance through which the common centre of gravity of a set of detached weights moves when one of the weights is shifted to a new position.

Rule.—*Multiply the weight moved by the distance through which its centre of gravity is shifted; divide the product by the sum total of the weights; the quotient will be the distance through which the common centre of gravity has moved in a line parallel to that in which the weight was shifted.*

Distance through which the Centre of Gravity shifts when any of the Cargo is lowered or raised. Example I.—There are 500 tons of cargo in the 'tween decks; 200 tons are moved into the lower hold, a depth of 8 feet below the 'tween decks, thereby lowering the centre of gravity of this 200 tons 7 feet, for the purpose of stiffening the ship. Find how much the centre of gravity of the 500 tons is lowered.

Weight shifted, $200 \times 7 = 1400$
Weight left in 'tween decks, 300
500

$$\text{Therefore, centre of gravity lowered} = \frac{1400}{500} = 2\tfrac{4}{5} \text{ feet.}$$

Distance through which the Centre of Gravity is lowered by sending Spars and Rigging on Deck. Example II.—The centre of gravity of a vessel in water ballast is 8 feet above the ballast-tanks, the tops of which are 3 feet above the top of the keel; the total weight of ship and ballast is 2500 tons. Supposing the centre of gravity of all the spars and rigging above the lower masts to be 45 feet above the deck, and the weight to be 20 tons, how much will the common centre of gravity be lowered by sending down on deck, masts, yards, sails, and rigging?

Weight shifted, 20 tons $\times$ 45 = 900
Total weight, 2500 tons

$$\text{Therefore, centre of gravity lowered} \frac{900}{2500} = \frac{9}{25} \text{ feet, or } 4\tfrac{1}{3} \text{ inches.}$$

Example III.—A vessel and her cargo weigh 4000 tons; the centre of gravity of ship and cargo is 18 feet above the keel. In the 'tween decks is stowed 600 tons of cargo, while there is an empty space in the lower hold for 400 tons. How much will the common centre of gravity be lowered by striking 300 tons of the 'tween decks cargo into the lower hold, whereby its centre of gravity is lowered 8 feet?

Total weight, 4000

Weight shifted, 300 × 8 = 2400 = moment.

Therefore,

$$\text{Centre of gravity lowered } \frac{2400}{4000} = 0{\cdot}6 \text{ feet, or } 7{\cdot}2 \text{ inches.}$$

Distance through which the Centre of Gravity is raised by Stowing Cargo on Deck. Example IV.—The weight of a ship and cargo is 5000 tons, and the common centre of gravity is 16 feet above the keel. How much will the centre of gravity be raised by stowing on deck 400 tons of coal, whose centre of gravity is 25 feet above the keel?

$$\begin{array}{lrcl} \text{Ship and cargo,} & 16 \times 5000 & = & 80000 \\ \text{Coal,} & 25 \times \underline{\;400\;} & = & \underline{10000} \\ & 5400 & = & 90000 \end{array}$$

$$\text{Common centre of gravity } \frac{90000}{5400} = 16{\cdot}66$$

Therefore, centre of gravity raised 16·66 − 16 = ·66, or 8 ins.

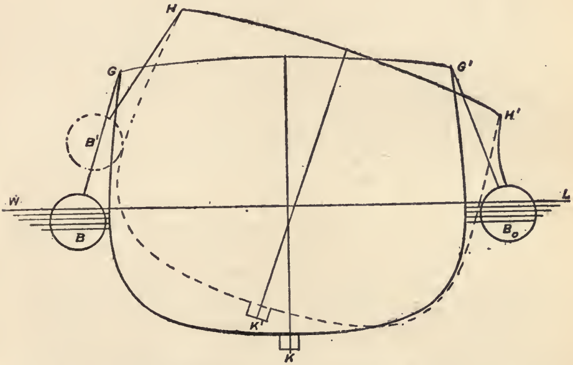
Movable Centres of Gravity. Temporary Stiffening for Crank Empty Ships.—A very effective practical method of automatically lowering the centre of gravity of a crank empty ship is employed in the Tyne Docks, Newcastle.

When a ship will not stand up with clean-swept hold, two large booms, formed of several baulks of timber built together and hooped with iron, having large ring-bolts at each end, are hung up alongside, one on each side of the ship; to each end of these booms is hooked a tackle from the gunwale. These tackles are hauled sufficiently taut to take part of the weight of the booms, and made fast. Any tendency on the part of the ship to list is counteracted by the weight of the boom, which she has to lift out of the water on the side opposite to which she lists; while the side listed to is entirely relieved from the weight of the boom on that side, owing to its being floated by the water, and slacking up the tackles hanging it.

It will be apparent that the principle of the plan is an automatically movable centre of gravity provided to the ship; for when the ship lists her centre of gravity moves or is carried downwards and outwards to the high side by the weight of the boom at the water's edge. Crank ships are thus maintained in an upright position for the purpose of transporting about the docks, hauling under the *coal-shoots* or *tips*, and avoiding damage to these and to other vessels in their vicinity.

The diagram below (Fig. 20) will illustrate what has been described. GKG′ is a transverse section of the ship upright, B and B_0 are the two booms hung by the tackles BG B_0G'. WL is the water line. Suppose the vessel now to heel over to the position HK′H′, shown by the dotted section; then B is lifted into the position B′ by the tackle HB′, while the tackle $G'B_0$ is slackened up to the position $H'B_0$, allowing B_0 to float by its own buoyancy. The figure is an exaggeration for the purpose of illustration. In practice, the vessel cannot heel unless she were pressed over by a heavy squall, after whose passage she would immediately recover her upright position. The change in the position of the ship's centre of gravity due to the attached booms has not been dealt with here, but it may be ascertained for the upright position with one boom alongside, provided the ship's centre of gravity, her displacement or weight, and the weight of the boom are known. (*See* article "Centre of Gravity.")

FIG. 20.



The great practical convenience of these booms is, that the ship is enabled to remain in dock without ballast in her holds, whereby she suffers no loss of time by having to discharge ballast before she completes her loading; also that she can be maintained in a stable condition by two or three hands, who keep the boom tackles taut.

CHAPTER VIII.

THE RELATIVE STRENGTH OF ROPE.

Strength of Rope.—*To find the safe working load for new three-stranded rope.*

RULE.—*Square the circumference of the rope and divide by 7 for the working load in tons.*

Thus, a 4-inch rope gives $\frac{4 \times 4}{7} = \frac{16}{7} = 2\frac{2}{7}$ tons.

A 5-inch rope gives $\frac{5 \times 5}{7} = \frac{25}{7} = 3\frac{4}{7}$ tons.

An 8-inch rope gives $\frac{8 \times 8}{7} = \frac{64}{7} = 9\frac{1}{7}$ tons, and so on.

When the load is given and it is required to find the necessary size of the rope, we have the reverse of the above rule.

RULE.—*Multiply the given load by 7 and extract the square root for the circumference of the rope.*

Thus, suppose the given load is $2\frac{2}{7}$ tons—

$$2\tfrac{2}{7} \times 7 = 16, \ \sqrt{16} = 4 \text{ inches.}$$

Suppose the given load is 9 tons—

$$9 \times 7 = 63, \ \sqrt{63} = 8 \text{ inches nearly.}$$

To find what number of parts of a small rope is equal to a large rope.

RULE.—*Divide the square of the circumference of the large rope by the square of the circumference of the small rope; the result will be the number of parts of the small rope equal to the large rope.*

Thus: how many parts of a 3-inch rope will be equal to a 6-inch rope?

$$\frac{6 \times 6}{3 \times 3} = \frac{36}{9} = 4 \text{ parts of the 3-inch rope.}$$

EXAMPLE I.—The leach-rope of a foresail is 5-inch rope. How many turns of a two-inch earing would be equal in strength to the leach?

$$\frac{\text{Leach-rope}}{\text{Earing}} \quad \frac{5 \times 5}{2 \times 2} = \frac{25}{4} = 6 \text{ turns.}$$

To find what weight a rope will hang when rove as a tackle.

RULE.—*Multiply the weight the rope is capable of hanging, by the number of parts at the travelling block; the product will be the result required.*

EXAMPLE I.—A 5-inch rope will hang a load of $3\frac{4}{7}$ tons; what will it hang when rove as a tackle having 6 parts at the travelling block?

$$3\tfrac{4}{7} \times 6 = 21\tfrac{3}{7} \text{ tons.}$$

Steel wire rope may be considered as approximately equal to tarred hemp, or manilla rope of three times the size. Thus, a 4-inch steel wire is equal to a 12-inch hemp rope.

TABLE OF STEEL WIRE ROPE COMPARED WITH TARRED HEMP ROPE, AND ALLOWED BY THE BUREAU VERITAS.

TABLE I.

Size of Steel Hawser.	Equal to Tarred Hemp Hawser.	Breaking Strain of Steel Hawsers.
Circumference 2½ inches	Circumference 7½ inches	12½ tons.
,, 2¾ ,,	,, 8½ ,,	15 ,,
,, 3 ,,	,, 9 ,,	18 ,,
,, 3¼ ,,	,, 10 ,,	22 ,,
,, 3½ ,,	,, 11 ,,	26 ,,
,, 4 ,,	,, 12 ,,	33 ,,
,, 4½ ,,	,, 13 ,,	39 ,,

The following table gives the safe working load for new tarred hemp, calculated by the rule given that circumference $^2 \div 7$ equals the working load.

TABLE IA.

Size of Rope.	Safe Working Load.	Size of Rope.	Safe Working Load.
2 inch.	11·4 cwt.	9 inch	11·6 tons.
2½ ,,	18 ,,	10 ,,	14·3 ,,
3 ,,	1·3 tons	11 ,,	17·3 ,,
3½ ,,	1¾ ,,	12 ,,	20·6 ,,
4 ,,	2·3 ,,	13 ,,	24 ,,
4½ ,,	2·9 ,,	14 ,,	28 ,,
5 ,,	3·6 ,,	15 ,,	32 ,,
5½ ,,	4·3 ,,	16 ,,	36·6 ,,
6 ,,	5 ,,	17 ,,	41·3 ,,
6½ ,,	6 ,,	18 ,,	46·3 ,,
7 ,,	7 ,,	19 ,,	51·6 ,,
7½ ,,	8 ,,	20 ,,	57 ,,
8 ,,	9 ,,	22 ,,	69 ,,

The rule by which the above table is formed is that usually employed in the merchant service, but some practical men divide the square of the circumference by 6 for the work-load; however, the divisor 7 gives a safer margin.

For the breaking strain of a hemp rope, the square of the circumference divided by 4 gives a good approximation; the divisor 3 gives too high a breaking strain, so that the rope is likely to part before the given value is reached.

Safe Load for Steel Wire Rope.—The safe working strain for steel wire rope is one-sixth of the breaking strain. Thus a $2\frac{1}{2}$-inch steel wire rope has a breaking strain of 12 tons; hence the safe working strain would be 2 tons; a 4-inch steel wire would safely work $5\frac{1}{2}$ tons; and so on.

Deterioration of Hemp Rope.—The deterioration of hemp rope after a few months' wear renders it imperative that new rope should always be used to do heavy work on board ship, and the practice of reeving a used hawser for either a purchase tackle or topping-lift cannot be too strongly condemned; for, although the rope may upon careful examination appear perfectly sound to the eye, yet it may have sustained a loss of as much as 30 per cent. or upwards of its original strength. When new rope is sent on board for lifting purposes, it should be carefully protected from getting wet and stowed in as dry a place as possible; but should it unfortunately get wetted by either salt water or rain, it should be uncoiled and faked down to dry at the earliest opportunity.

When new tarred hemp has a reddish hue it is usually hard and has been made a long time; it is therefore most uncertain in its strength and may not be trusted.

The safe working factors given in the preceding rules are for sound rope of normal quality, but as this is not easily known in either coir, manilla, or hemp, it is always more certain to use the flexible steel wire rope for heavy work, since the strength is guaranteed; besides, the loss of power through friction in the purchase is very much less, in addition to which it is lighter and cannot be damaged by chafing against itself to any serious extent, whereas with the fibre ropes any unfairness in the leads may instantly ruin the rope and bring about a serious accident. Whatever prejudice exists against steel wire rope is confined solely to the old school of seamen, and is rapidly disappearing even there.

The Strength of Chain.—The strength of chain relative to rope is usually considered by seamen to be in the proportion of 10 to 1, *i.e.*, a 1-inch chain will be equal to a rope 10 inches in circumference, the diameter of the iron forming the link being the measure of the chain. Professor Jamieson* assigns 5 tons per square inch of section as a safe working tensile strain on iron rods, and 4 tons per square inch as a safe working shearing stress. Since chains may be subjected to both tensile and shearing stresses, we will adopt 4 tons per square inch of section for the safe working load of bar iron. Studded chains are considered equal in strength to twice that of a single bar having the same sectional area; for example, the safe working load for a stud chain made of bar iron 1 inch in sectional area = 2 × 4 = 8 tons. Hence the rule for finding the safe working load for stud chain :

$$\text{Load} = \text{diameter}^2 \times \frac{\pi}{4} \times 4 \times 2$$

RULE.—*Multiply the square of the diameter of the iron in the link by* 6·28; *the result will be the safe working load.*

EXAMPLE I.—Calculate the safe working load for $\frac{1}{2}$-inch stud chain.

$$\text{Safe load} = 6{\cdot}28 \times {\cdot}5^2 = 1{\cdot}57 \text{ tons.}$$

EXAMPLE II.—Calculate the safe working load for $\frac{3}{4}$-inch stud chain.

$$\text{Safe load} = 6{\cdot}28 \times {\cdot}75^2 = 3{\cdot}53 \text{ tons.}$$

To find the safe working strength of open, round, or oval-linked chain.—Square the diameter of the iron in the link expressed in eighths of an inch, and strike off the right-hand figure as a decimal, when there are two or three figures; if there is only one figure, it is a decimal. Thus, $\frac{1}{4}$-inch chain is equal to $\frac{2}{8}$; squaring 2 we get ·4 of a ton = 8 cwt. For the working strength of a $\frac{3}{8}$-inch chain we get 3^2 = ·9 of a ton = 18 cwt.; and for $\frac{1}{2}$-inch chain = $\frac{4}{8}$, we get 4^2 = 1·6 tons = 1 ton 12 cwt., safe working load.

The following table gives the approximate safe working strength of round and oval-linked chain without studs, calculated by the above empirical rule :

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* "Applied Mechanics (Elementary Manual of)." Chas. Griffin & Co., Exeter Street, Strand.

TABLE II.

Size of Chain.	Safe Working Strength.	Size of Chain.	Safe Working Strength.
$\frac{1}{8}$ inch.	2 cwt.	$\frac{13}{16}$ inch.	4·2 tons.
$\frac{3}{16}$,,	$4\frac{1}{2}$,,	$\frac{7}{8}$,,	4·9 ,,
$\frac{1}{4}$,,	8 ,,	$\frac{15}{16}$,,	5·6 ,,
$\frac{5}{16}$,,	$12\frac{1}{2}$,,	1 ,,	6·4 ,,
$\frac{3}{8}$,,	18 ,,	$1\frac{1}{16}$,,	7·2 ,,
$\frac{7}{16}$,,	1·2 tons	$1\frac{1}{8}$,,	8·1 ,,
$\frac{1}{2}$,,	1·6 ,,	$1\frac{3}{16}$,,	9·0 ,,
$\frac{9}{16}$,,	2·0 ,,	$1\frac{1}{4}$,,	10·0 ,,
$\frac{5}{8}$,,	2·5 ,,	$1\frac{5}{16}$,,	11·0 ,,
$\frac{11}{16}$,,	3·0 ,,	$1\frac{3}{8}$,,	12·1 ,,
$\frac{6}{8}$,,	3·6 ,,	$1\frac{7}{16}$,,	13·2 ,,

The Admiralty test strain for chain varies as the square of the diameter of the iron in the link. By means of this rule we may find the test strain of any cable when we know the test strain of another cable, whose size is given. Thus, the test strain of a 2-inch cable is 72 tons; from this we require to find the test strain of a 1-inch cable; therefore we have the proportion:

$$2^2 : 72 :: 1^2 : \text{to test of 1-inch cable},$$

Therefore,

$$\text{Test strain for 1-inch cable} = \frac{72}{4} = 18 \text{ tons},$$

which agrees with the Admiralty test, as will be seen by the accompanying tables.

This proportion does not hold in the actual breaking strain, which reaches its ultimate limit before the square of the diameter ratio has been attained.

The working strength of stud-linked chain in the accompanying tables is calculated from the formula already given.

$$\text{Safe working load} = \text{diameter}^2 \times 6{\cdot}28.$$

EXAMPLE I.—Find the safe working load for a 2-inch cable.

$$\text{Safe load} = 2^2 \times 6{\cdot}28 = 25{\cdot}12 \text{ tons}.$$

EXAMPLE II.—Find the safe working load for a $2\frac{1}{2}$-inch cable.

$$\text{Safe load} = (2{\cdot}5)^2 \times 6{\cdot}28 = 6{\cdot}25 \times 6{\cdot}28$$
$$= 39{\cdot}25 \text{ tons}.$$

TABLE III.—OF SAFE WORKING STRENGTH OF STUD-LINKED CHAIN CABLES WITH THE ADMIRALTY PROOF TEST AND A BREAKING STRAIN.

Size of Chain.	Safe Working Strength.	Admiralty Proof Test.	Breaking Strain.
Inch.	Tons.	Tons.	Tons.
$\frac{11}{16}$	3·0	8·5	12·75
$\frac{12}{16}$	3·5	10·1	15·1
$\frac{13}{16}$	4·0	11·9	17·8
$\frac{7}{8}$	5·0	13·7	20·7
$\frac{15}{16}$	5·6	15·8	23·7
1	6·2	18	27
$1\frac{1}{16}$	7·0	20·3	30·4
$1\frac{1}{8}$	7·9	22·7	34·1
$1\frac{3}{16}$	8·8	25·4	38
$1\frac{1}{4}$	9·8	28·1	42·1
$1\frac{5}{16}$	10·8	31	46·5
$1\frac{3}{8}$	11·8	34	51
$1\frac{7}{16}$	13·0	37·1	55·7
$1\frac{1}{2}$	14·2	40·5	58·7
$1\frac{9}{16}$	15·2	43·9	61·4
$1\frac{5}{8}$	16·5	47·5	66·5
$1\frac{11}{16}$	17·8	51·3	71·75
$1\frac{6}{8}$	19·2	55·1	77·1
$1\frac{13}{16}$	20·8	59·1	82·75
$1\frac{7}{8}$	22·1	63·3	88·5
$1\frac{15}{16}$	23·6	67·5	94·5
2	25·2	72	100·8
$2\frac{1}{16}$	26·8	76·5	107·7
$2\frac{1}{8}$	28·4	81·3	113·75
$2\frac{3}{16}$	30·1	86·1	120·5
$2\frac{1}{4}$	31·8	91·1	127·5
$2\frac{5}{16}$	33·6	96·3	134·75
$2\frac{3}{8}$	35·6	101·5	142·1
$2\frac{7}{16}$	37·2	107	149·7
$2\frac{1}{2}$	39·2	112·5	157·5

Effects of Frost on Iron.—Amongst engineers there is much difference of opinion respecting the effects of severe frost in rendering iron more brittle and liable to fracture ; but, so far as these experiments have been carried, they have not yet succeeded in giving a decided negative to the popular belief that frost does make chains more brittle and less capable of withstanding jars. Although Professor Dewar has shown that the cohesion of the molecules of iron is greater at very low temperature, and increases as the temperature decreases, nevertheless the experience of practical men does not show that this increased cohesion among the molecules is accompanied by an increased resistance to fracture by sudden jars and vibrations. It is well known among sailors that the jarrings and vibrations to which winch chains, chain slings, steering-rods, boats' davits, topsail sheets, &c., are subjected render them more brittle; and a fracture shows a short crystallised surface instead of a fibrous tear, which usually gives some warning before parting altogether. This brittleness acquired by the iron is usually remedied by passing the iron through the fire, which restores it to its original tenacity. A necessary precaution, therefore, is to have all winch chains, chain slings, and steering-rods and chains periodically passed through the fire in order to minimise the risk of accident to life and property.

Doubtless wrought iron is more ductile in warm weather, a fact which to some extent justifies the popular belief in the prejudicial effects of frost upon its tenacity.

CHAPTER IX.

DERRICKS AND SHEARS.

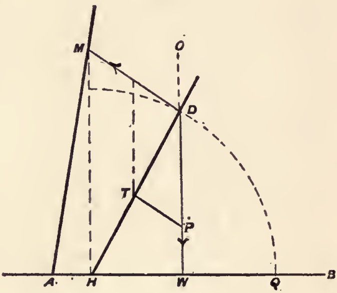
Rigging Derricks.—In proceeding to rig a derrick for lifting heavy weights, the first thing to be considered is the weight to be lifted; then the strain that will come upon the running part of the fall of the purchase employed. With a purchase of two treble blocks, if the fall leads through a block at the heel of the derrick, there will be six parts at the travelling block and the weight upon the derrick will be a maximum. since it will be equal to the weight lifted *plus* the strain on the fall, *plus* the weight of the purchase and slings. It will therefore greatly relieve the derrick and topping-lift if the purchase is rove with the hauling part at the lower or travelling block and is then taken out through a single block at the head of the derrick, next through another block at the topmost head down to the winch. This plan increases the power of the tackle from 6 to 7, in addition to relieving the thrust on the derrick and the strain on the topping-lift. But for the sake of the fall itself the block at the masthead should have a sheave of not less diameter than those in the tackle.

Most ships' masts have a rake, and, even when they may be upright, the ship may be trimmed some inches by the stern; therefore, to secure easy swinging in the derrick, a plumb-line should be hung from the point where the topping-lift is lashed on the mast, and the derrick if possible stepped at the point where this line touches the deck. Unless this is done, the derrick, when abaft the mast, will be difficult to swing over the side, owing to its tendency always to hang amidships; this is caused by the fact that a plumb-line through the centre of gravity of the system is always perpendicular to the horizon, and it is only when the derrick is hanging amidships that this line lies in the plane in which lie the derrick, topping-lift, and weight, because as the derrick is swung over the ship's deck the plane in which it and its rigging lie no longer coincides with the perpendicular plane passing through its centre of gravity and the weight at its head, but becomes inclined to the latter, and the pull-back is represented by the sine of the angle between the two planes. When the derrick is rigged forward of a raking mast its tendency will be to swing over the side the moment it passes out of the vertical midship plane, for the reason already given. This latter tendency is an advantage in putting weights out, and the former in taking weights in.

When possible, the shoe of the derrick should be butted against the mast partners or hatch-combing on the side to which the thrust will be directed, or it may be cleated to prevent it slipping. In the swinging derrick the heel of the derrick must also be securely lashed with cleats under the lashings to prevent them from slipping down, since they must be slack enough to allow the derrick to be lowered or topped up.

Finding the Strains upon Derricks and their Rigging by Construction.—In finding the strains upon a swinging derrick and its rigging by construction, the method of the parallelogram of forces will be employed, as it is simpler than the method of the bent lever and does not require so much calculation.

FIG. 21.



Draw a horizontal line AB, and from A draw AM to represent the mast, giving it the necessary rake. Let H be the point at which it is intended to step the derrick and M the point in the mast where the topping-lift is lashed; lay off from H along the line AB the distance HW of the weight to be raised, from H the heel of the derrick: from W erect a perpendicular line WO; with the length of the derrick from the heel to the upper purchase block in a pair of compasses and with H as a centre describe the arc DQ: where it cuts the vertical line WO at D is the position of the derrick for lifting the weight W; join HD to represent the derrick, and MD to represent the topping-lift. From D lay off towards W as many units DP of any convenient scale as there are tons in the weight which will be put on the derrick head, and draw PT parallel to the topping-lift;

DT will be the thrust on the derrick, and PT the strain on the topping-lift, in tons measured on the same scale. If the derrick has to be lowered for the purpose of clearing the ship's side, its head will still be in the arc DQ; hence it is only necessary to erect a perpendicular at the distance required for this purpose, from the heel of the derrick, and where it cuts the arc will be the position of the derrick head from which the topping-lift is drawn to M, and the construction completed as before for the thrust and strain.

Characteristics of Shears.—Shears may be considered as two derricks mutually supporting each other in a lateral direction. When the shears have a drop they may be conceived as a single derrick stepped midway between the two legs and in the same plane; by the method already described, the thrust upon this imaginary derrick is found and again resolved into its components parallel to the shear legs which represent the thrust upon the legs to which they are respectively parallel.

Examples of Derricks. EXAMPLE I.—A derrick has the upper purchase block lashed at 30 feet from the heel, which is stepped 12 feet from the weight, 14 tons, to be lifted and put over the side, to clear which, the purchase must plumb a point 20 feet from the heel. The fall leads to the top-mast head 60 feet above the deck; there are seven parts at the lower block, and two leading blocks are used, making eight sheaves to be allowed for. Required the strains upon the fall, the topping-lift, and thrust on the derrick for both positions of the derrick, when the topping-lift is secured to the mast 40 feet above the deck, also the size of the rope and the strain it will have to bear.

Here the weight to be lifted is 14 tons, with 8 sheaves in use, but the leading block at the derrick head may be neglected, since it takes the rope very little out of a straight lead; we shall therefore only allow for 7 sheaves, which, by the rule given in the chapter on tackles, gives the—

$$\text{resistance} = 14 + \tfrac{7}{8}\,14 = 26{\cdot}25 \text{ tons.}$$

Now there are 7 parts at the travelling block; therefore, the power is $\frac{1}{7}$ of the resistance; hence—

$$\text{Power} = \frac{26{\cdot}25}{7} = 3{\cdot}75 \text{ tons to be applied to the fall.}$$

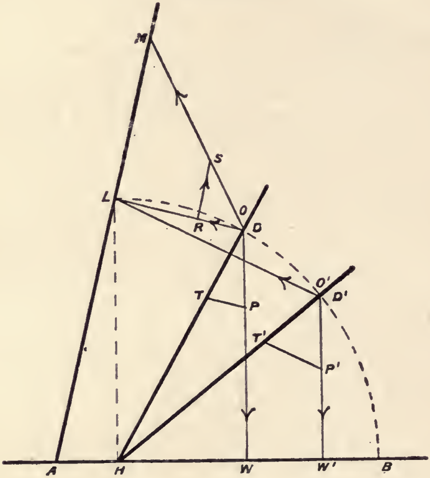
To find the size of rope required we get from the chapter on the strength of rope—

$$\sqrt{3{\cdot}75 \times 7} = \sqrt{26{\cdot}25} = 5{\cdot}12 \text{ inch rope,}$$

since the rope required is above 5 inches we may use a 6-inch.

It is usual to add half the weight of the derrick and the weight of the purchase slings, &c., to the weight to be lifted, for the weight on the derrick head; we will therefore in this case allow $\frac{1}{2}$ a ton for the derrick and another half-ton for the gear, which gives 15 tons.

FIG. 22.

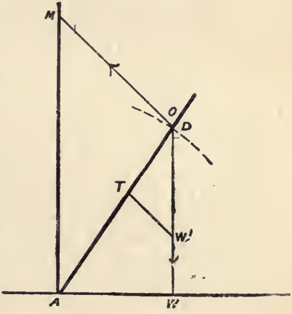


Draw the line AB, erect AM to represent the mast, and from any scale lay off AM = 60, AL = 40; take the point H for the heel of the derrick, and along AB lay off HW = 12, HW′ = 20, the points which the derrick will plumb when lifting and clearing the side; from these points draw perpendicular lines WO and W′O′; with the length of the derrick = 30 as radius and H as a centre describes the quadrant LDB; where the quadrant is cut by the line WO is the position of the derrick for lifting; join DH to represent the derrick, and DL to represent the topping-lift; from D along DW lay off DP = 15; through P draw PT parallel to the topping-lift; then, on the same scale, PT = 6·7 tons strain on the topping-lift, and DT = 11·4 tons thrust on the derrick. Next join DM to represent the lead of the fall. From D along DM lay off DS = 3·75, the strain upon the running part; from S let fall a perpendicular SR on the topping-lift, then DR = 3·5, the quantity by which the fall relieves the topping-lift; hence we get for the actual strain upon it 6·7 − 3·5 = 3·2 tons; the perpendicular RS will nearly represent the relief upon the thrust of the derrick and gives 1·5 tons; therefore the actual thrust becomes about 10 tons. Now join D′H to represent the derrick plumbed over the side; make D′P = 15; then will P′T′ = 9·7 and D′T′ = 11·4; and we may consider the strain upon the fall resolved upon the topping-lift as equal to that already obtained for the first position. Collecting we get—

Strain on running part of fall . .	=	3·75	tons.
Size of rope	=	6	inch.
Strain on topping-lift when lifting .	=	3·2	tons.
Thrust on derrick ,, ,, .	=	10	,,
Strain on topping-lift for overside .	=	6·2	,,
Thrust	=	10·4	,,

Example II.—A weight of 10 tons has to be discharged by means of a derrick; the purchase is two treble blocks; the upper block is 36 feet from the heel of the derrick and the topping-lift is lashed 36 feet above the deck. The purchase must plumb a point $24\frac{1}{2}$ feet from the heel of the derrick to clear the ship's side, and the fall is rove through a block at the heel; required the strain upon the topping-lift and the thrust on the derrick when in this position, also the power to be applied to the fall and the size of the rope for both topping-lift and fall.

Fig. 23.



Draw a horizontal line AW, make AW = 24·5; erect the perpendicular AM, which make = 36; at W erect another perpendicular and take 36 as a radius; with A as a centre describe an arc cutting WD in D; join DA to represent the derrick and DM to represent the topping-lift.

The strain upon the hauling part of the fall will be—since there are 7 sheaves in use, and half a ton is added to the weight for the gear—equal to—

$$\frac{10\cdot5 + \frac{7}{8}\,10\cdot5}{6} = \frac{19\cdot6}{6} = 3\cdot3 \text{ tons nearly,}$$

which we may call $3\frac{1}{2}$ tons; since this pull is along the derrick to the heel, it should be resolved along the tackle and this component added to the load on the derrick head; but in practice this may be neglected, and we shall be on the side of safety if we add the whole pull on the fall to the load on the derrick head, therefore—

$$10\cdot5 + 3\cdot5 = 14 \text{ tons.}$$

Lay off on DW′, the weight = 14; through W′ draw WT parallel to the topping-lift DM, on which we get the strain W′T = 10 tons, and the thrust DT = 14 tons on the derrick AD.

The strain of the purchase fall is 3·3 tons; therefore the size of the rope required will be—

$$\sqrt{3\cdot3 \times 7} = \sqrt{23\cdot1} = 4\cdot8 \text{ inch,}$$

which we may call a 5-inch rope.

The strain on the topping-lift is 10 tons, and it will be necessary to have the topping-lift of sufficient strength to heave up the derrick with the weight hanging to it if required, therefore—

$$\text{Resistance} = 10 + \tfrac{6}{8}\,10 = 17\cdot5.$$

$$\text{Therefore the power} = \frac{17\cdot5}{6} = 3 \text{ tons nearly.}$$

$$\text{Size of rope} = \sqrt{3 \times 7} = \sqrt{21} = 4\cdot6 \text{ inch.}$$

Collecting the results, we get—

Thrust on the derrick 14 tons,
Strain on topping-lift 10 tons,
Weight on the fall $3\frac{1}{2}$ tons nearly,
Weight on topping-lift fall in heaving up, 3 tons nearly.
Size of fall 5 inch, size of topping-lift fall $4\frac{1}{2}$ inch.

The weight on the topping-lift fall in lowering would be $= \frac{10}{6}$ or $1\frac{2}{3}$ tons only, and even less, for the derrick would have to overcome the friction in overhauling the tackle.

Example of Shears. Example III.—A pair of shears has a vertical height of 30 feet and a spread of 20 feet at the heels; the head plumbs a point 8 feet forward of the heel; the back guy has a rise of 4 feet for every 10 feet of its length; the purchase is two treble blocks and the fall leads direct from the upper block to a winch placed 10 feet behind the shears. The weight to be lifted is 16 tons, including the gear. Find the thrust on the shear legs and the strain on the back guy (neglecting the assistance it gets from the lead of the fall), also the strain on the fall and the size of rope required.

Here we have 6 parts at the travelling block; therefore, the power required for the hauling part of the fall is—

$$\frac{16 + \frac{6}{8}\,16}{6} = \frac{16 + 12}{6} = 4\tfrac{2}{3} \text{ tons};$$

adding this to the weight to be lifted we get 16 + 4·66 tons, or 20·66 tons on the derrick head.

FIG. 24.

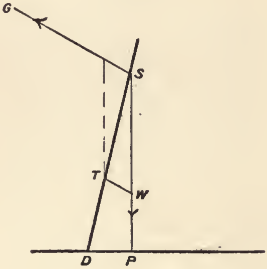


FIG. 25.

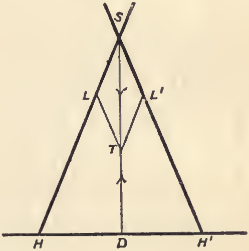
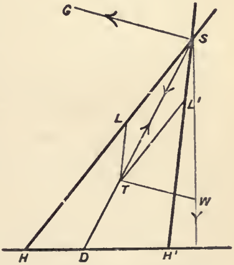


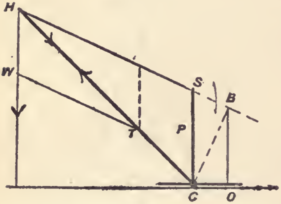
FIG. 26.



For the construction, draw a line DP (Fig. 24); make DP = 8 feet for the rake of the shears; from P erect a perpendicular PS = 30 feet; join DS, which will be the derrick representing the shears; from S draw SG = 10 feet, giving it a rise at G of 4 feet above S. On SP lay off SW = 20·66 to represent the weight; draw WT parallel to SG, then WT will be the strain on the guy and ST the thrust on the derrick, respectively = 5·3 and 19·5 since DP = 8 feet and SP = 30 feet, we find from the traverse table SD = 31 feet; therefore, upon a horizontal line (Fig. 25), erect DS = 31 feet; from D lay off DH, DH′, each = 10 feet, the spread of the shears; join SH and SH′ for the shear legs. From S lay off ST = 19·5 tons; through T draw TL, TL′ parallel to the legs of the shears; the side TL or SL = 11½ tons represents the thrust on each leg. The whole system is represented in the figure (Fig. 26).

Cranes considered as Derricks.—The strains upon a crane may be found by the parallelogram of forces, or by the bent lever; when only the strain on the stays and the thrust on the jib are required, the parallelogram may be most conveniently used. But when it is required to find the counterpoise for a given lift, the method of the bent lever must be used.

FIG. 27.



In the figure, SC is the pivot shaft, HC the jib, SH the stays, and HP the runner, not drawn in the figure. The strains are found by laying off HW equal to the load, and drawing WT parallel to the stays which will be equal to the strain upon them; HT will be the thrust on the jib; but the strain on WT, or the stays will be relieved by the power applied to the runner, since it is nearly in line with the stays.

To find the counterpoise necessary for a given load on the crane. Produce HS in the direction of B; from C draw a line CB perpendicular to the stays HS, produced; then BC and CH are the two arms of a bent lever with fulcrum C. Let fall perpendiculars from H and B meeting the horizontal plane in G and O, then GC, OC are the two effective arms of the bent lever; therefore the counterpoise at O is equal to the load W multiplied by GC and divided CO, *i.e.*,

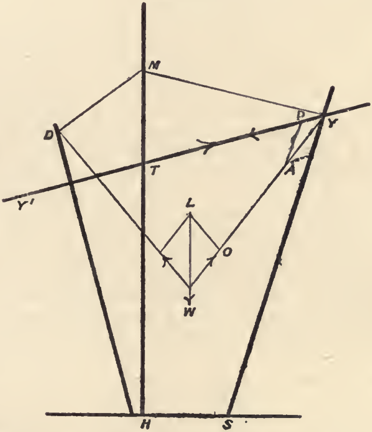
$$\text{load} \times \text{GC} = \text{counterpoise} \times \text{CO}.$$

When the counterpoise has its centre of gravity at O it will be equal to the strain on the stays, but the farther it is removed from the fulcrum C, the less will be the weight necessary to balance the crane.

The hydraulic cranes about the docks have the counterpoise at the point B for the purpose of clearing obstacles when swinging.

Yard-arm and Midship Derricks.—When a heavy weight has to be put out from the main hatch of a sailing vessel, the system employed is usually a midship derrick for lifting out of the hatch, and a yard-arm derrick for putting over the side. The midship derrick is stepped on a well-shored-up beam close to the mast partners, and the yard-arm derrick is stepped close up to the waterways, and over a beam also well shored up; the main yard is untrussed, topped up, and securely lashed to the mast, while the yard-arm derrick is lashed to the yard sufficiently far out to clear the weight from the ship s side.

FIG. 28.



In the figure, let HTM be the mast, YY' the yard lashed to the mast at T; HD is the midship derrick and DM its topping-lift; YS is the yard-arm derrick lashed to the yard at Y, and YM its topping-lift.

When the weight is being swung over the side, the topping-lift YM will have no weight upon it until the weight being lifted has swung outside the derrick YS.

Suppose the weight to be hanging to both tackles, half-way between the hatch and the ship's side, at the position W; then the tackles DW, YW form a span. From W draw WL containing as many units of length as there are tons in the weight W and complete the parallelogram: OW will represent the strain upon the tackle YW. Now from Y lay off YA equal to OW and from A draw AP parallel to the derrick YS; then PY will be the thrust upon the yard and therefore the strain which the lashing at the slings will have to bear when the weight is at W: hence the reason for untrussing the yard. The midship derrick DH may be allowed to swing free to ease the thrust on the yard-arm and reduce the strain on the outer tackle. The strains upon the topping-lifts and the thrusts upon the derricks when each is hanging the whole weight, may be found by the methods already given for single derricks.

It may be here remarked that in the above system the derricks are always nearly up and down, therefore but little strain is thrown on the derrick topping-lift, hence the sum of the power applied and the weight lifted are almost wholly expressed in thrust on the derrick. There is therefore no necessity to overhamper the derricks with too heavy topping-lift lashings, especially on the yard-arm derrick, since the lashing of the derrick to the yard and the lashing of the yard to the mast have both to bear the thrust on the yard when the weight is being hove out; they will, therefore, bear the strain put upon them when the weight is plumbed over the side, and instead of having a topping-lift lashing, consisting of about six turns of a hawser and about double the strength of the purchase tackle, it may be limited to a single three-inch steel wire pennant.

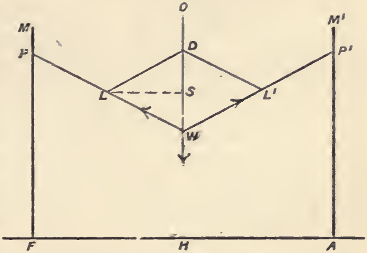
The system of midship and yard-arm derricks is the best for discharging heavy weights when a swinging derrick cannot be conveniently rigged, and should always be used in preference to the system which has a pair of shears for putting over the side, for the latter are always wanting in stability, both in stepping and staying, neither can any supporting lead for the hauling part of the fall be obtained, although it has been attempted by taking both ends of the falls to the winches, but this reduces the power of the tackle to one-half. However, two tackles may be used, and the falls led so as to oppose each other in capsizing the shears.

Strains upon Spans found by Construction and by the Traverse Tables. *To find the strain upon a span by construction.*—Draw a horizontal line, FA; make FA = to the distance between the masts, and FH the distance from F of the point plumbed by the tackle; draw FM and AM′ to represent the masts; on these lay off FP AP′, equal to the height at which the span is lashed; next draw a vertical line HO, upon which lay off HW, the height of the span above H; join PW and P′W; from W lay off WD, equal to the weight the span will have to bear, and complete the parallelogram WLDL′. WL or DL is the strain upon the span.

By the Traverse Table.

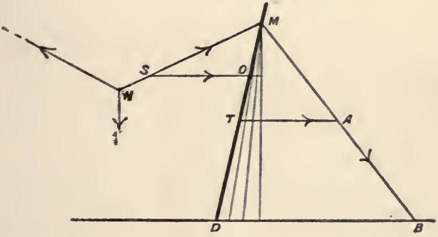
Draw LS perpendicular to WD, then WS is equal to half the weight; the angle LWS is found by taking the difference between PF and WH as a difference of latitude and FH as a departure; the course found for these will be the angle LWS; under this course, with half the weight, WS as a difference of latitude will be found in the distance column WL equal to the strain upon the span in tons. The rule supposes that the angle LWS is equal to the angle L′WS, which can only happen when W is in the middle of the span and PF = P′A; therefore, when these conditions do not exist the method of construction is the easier.

FIG. 29.



When a span is rigged between the main- and fore-masts for heavy work, the strain on the main rigging will be very great; hence it will be necessary to stay the main-mast with two tackles or pennants, taking them as far aft as possible, for the better support of the mast.

FIG. 30.

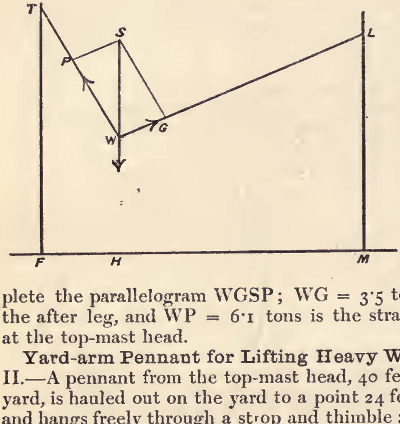


To find what strain will be thrown on the temporary stay tackles.—Draw DM to represent the mast (Fig. 30), MW the span. From M lay off MS equal to the strain upon the span; from S draw the horizontal line SO; this represents the horizontal pull upon the mast. Draw MB to represent the tackle, DB being the distance from the mast at which the tackle is hooked; parallel to SO draw TA equal to SO; then MA will be the strain upon the tackle. A similar process will give the strain upon the fore-stay, but that is usually capable of bearing the strain put upon it.

Example I.—The point to be plumbed by a span is 25 feet abaft the fore-mast; a pennant is lashed to the fore-top-mast head at 60 feet above the deck. Another pennant is lashed to the main-mast head at a height of 35 feet above the deck; the distance between the two masts is 85 feet; the bight of this span is 20 feet above the deck at the point plumbed by the tackle; find the strains upon the pennants when there is a weight of 6 tons on the upper block of the tackle.

In Fig. 31, make FM = 85 feet, FH = 25 feet, FT = 60 feet, ML = 35 feet; H is the point to be plumbed by the tackle; make HW = 20 feet and join TW, LW; these represent the legs of the span; produce HW upwards and make WS = 6 tons in units of the scale used, and upon WS, as a diagonal, complete the parallelogram WGSP; WG = 3·5 tons is the strain on the after leg, and WP = 6·1 tons is the strain on the pennant at the top-mast head.

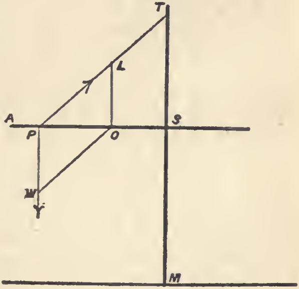
Fig. 31.



Yard-arm Pennant for Lifting Heavy Weights. Example II.—A pennant from the top-mast head, 40 feet above the lower yard, is hauled out on the yard to a point 24 feet from the slings, and hangs freely through a strop and thimble; the yard is square on the lifts. The pennant has to sustain a weight of 3 tons. What will be the strain on the pennant, and on the strop and thimble?

In Fig. 32, let MST be the mast, AS the yard-arm. Make ST = 40 feet and SP = 24 feet; join TP to represent the pennant; make PW = 3 tons and complete the parallelogram PWOL; then PL = $3\frac{1}{2}$ tons is the strain on the pennant, and PO = 1·8 tons is the strain on the strop and thimble, and is equal to the thrust on the yard, which sustains none of the vertical weight, but merely acts as an outrigger. The traverse table may be conveniently used in solving this case, for we have PS as a departure and ST as a diff. lat. to find the course, which is the angle PTS = angle PLO; and since LO = PW we have LO as a diff. lat. and the course PLO to find the dist. = PL, and dep. = PO.

FIG. 32.



PLO = 31°, PL = 3·5 tons, PO = 1·8 tons.

Slinging Boats in Spans. EXAMPLE III.—A boat weighs 7 cwt., and is being hoisted by a span rove through the ring-bolts in the stem and the stern; there is no girth-strop round the boat to relieve the weight. What will be the strain upon the span when the legs make with each other an angle of 140° at the point where the tackle is hooked? Also, what will be the force exerted by the span in compressing the boat in the direction of her length?

Here we have only to consider a span inverted and the weight which it supports, represented by the weight of the boat acting at the hook of the tackle.

The traverse table affords the readiest means of solution. Take half the angle of 140° = 70° as a course, and half the weight of the boat, 7 cwt., as a difference of latitude = 3·5 cwt.; in the distance column will be found the strain on the span = 10·2 cwt. Also the compressing force will be found in the departure column = 9·7 cwt. This shows that the boat may be seriously injured by such a mode of slinging, therefore a girth-strop or lashing should always bear the greater weight, while the fore and aft span is merely used to prevent tipping and to keep the girth lashing in position.

In the above example we have given the angle between the two legs of the span, but in practice there would be neither time nor convenience for ascertaining this; we therefore approach the problem in another way. Since we can readily measure the length of the span and the height of its crutch or point where the tackle is hooked above the horizontal line joining the two ring-bolts to which the span is hooked, we may suppose, in the above example, that the length of the span was 23·4 feet, and the height of its crutch when the boat's weight was hanging in it to be 4 feet above the horizontal line joining the ring-bolts; we find the strain upon the span by taking half the length of the span, 11·7 feet, as a distance, and the height, 4 feet, as a difference of latitude, the course corresponding to these will be half the angle between the legs of the span, viz., 70°; with this course and half the weight of the boat, 3·5 cwt., in a difference of latitude column we get the strain on the span in a distance column = 10·2 cwt., the same as before, and the compression strain in a departure column = 9·7 cwt.

Or another way: when the length of the span and the distance between the ring-bolts in the end of the bolt are given, which, suppose in the example, are 23·4 feet and 22 feet respectively.—Take half these measures, viz., 11·7 and 11, enter the traverse table with 11·7 as a distance and 11 as a departure; over the course corresponding to this, find the distance corresponding to 3·5 cwt. in a diff. lat. for the strain on the span, viz., 10·2 cwt.

Example IV.—A span, the two legs of which enclose an angle of 170°, has to bear a strain of 13 tons; find the strain upon the span by traverse table and by construction.

The answer by the traverse table is given here:

With the half of 170° (*i.e.*, 85°) enter the traverse with this as a course and the half of 13 (*i.e.*, 6·5) as a difference of latitude, and the distance column will give the strain on the span

= 75 tons.

Now, this example is given to show the enormous strain thrown upon a span when it is very straight; for the weight to be lifted is only 10 tons, and 3 tons strain upon the running part of the fall makes up the 13 tons. If we refer to the table of steel-wire rope we shall find that such a load would be half the breaking strain of an 8-inch steel wire.

Application of the Span to a Ship's Cables when she is moored.—The principle of the span applies to ship's cables when the ship is moored with an open hawse in the direction from whence comes the strongest wind and sea.

If we take the last example of the span and suppose it to represent a ship's two cables laid out to make with each other an angle of 170°, and that the breaking strain of each cable is 75 tons; then we see that under such conditions the combined strength of the cables is equal only to 13 tons; whereas one cable growing ahead would bear a strain of 75 tons before breaking, and the two cables growing ahead would be equal to a strain of 150 tons.

It may be stated generally that the nearer the angle between the legs of any span approaches 180° the weaker will be the span, and the nearer the legs approach being parallel to each other the stronger it will be. If it is at all possible, an outrigger and pennant should be used in preference to a span when heavy weights are to be raised.

Experiments with Spans.—The property of the span may be readily illustrated by a simple model. Take two small blocks, say boat's blocks, and secure them to a bulkhead or other wall surface; through these blocks reeve a small line and hang any given weight on the bight between them (see Figure 8): let this weight be supported by weights made fast to the ends of the line. With a piece of chalk draw on the bulkhead a picture of the span, and from the weight, perpendicularly upward, draw a chalk line, lay off on this line as many inches as there are pounds in the weight on the bight of the span, complete the parallelogram, and the sides will contain as many inches as there are pounds on the end of the line, supposing there is no loss by friction in the system. By changing the relative positions of the blocks, and by altering the weights on the ends of the line, every possible form of span may be illustrated (see Figure 4), and cannot fail to prove instructive. Another method of illustration is with two small spring balances, each hung to a nail on the bulkhead and a piece of line bent on to their hooks for a span; to the bight of this line is hung a weight, when the index scales of the balances will show the strain upon the respective legs of the span, and verify the figure drawn upon the bulkhead more accurately than in the block system, since in the spring balance there is no friction. If the span represents the direction of a rope through a leading block, then the weight on the bight of span will be the strain on the hook or strop of the leading block for that lead; from this it is evident that the strain on the strop of the leading block is greatest when the two parts of the rope are parallel to each other.

1. The legs of a span make with each other an angle of 70°, and the vertical line through the weight supported by it divides this angle equally; what will be the strain on the span when it supports a weight of 15 tons? *Ans.*, 9 tons on each leg.

2. The distance between the masts supporting the span is 100 feet, one span leg is lashed at a point 40 feet higher than the other, and the weight to be lifted is distant in a horizontal direction 30 feet from the higher span leg; what are the strains on the span legs when supporting 12 tons, the lower span being horizontal? *Ans.*, 15 tons and 9 tons.

3. A ship is moored with 60 fathoms of cable each way; the angle between the cables is 150° and the ship is hanging equally to both. Find what strain they are thus capable of sustaining, supposing the breaking strain of each to be 70 tons. *Ans.*, 36·2 tons.

4. A span from the top-mast head making an angle of 35° with the perpendicular to the horizon is kept in position by a guy leading aft, and which makes with it an angle of 145°. Find the strains upon the span and the guy when hanging a weight of 18 tons. *Ans.*, 18·4 tons on guy, 29 tons on span.

5. A derrick is supporting a load of 14 tons at a point 41 feet from the heel; the topping-lift is lashed to the mast at 41 feet above the deck. Find the strain on the topping-lift and the thrust on the derrick when it is heeled 10° from the upright position. *Ans.*, 2 tons on topping-lift, 13·8 tons thrust.

6. The same derrick is heeled to 35° from the upright. Find the strain on topping-lift and thrust on the derrick. *Ans.*, 8½ tons strain, 14 tons thrust.

7. Again the same derrick is heeled to 67° from the upright. Find the strain on the topping-lift and the thrust on the derrick. *Ans.*, strain 15½ tons; thrust 14 tons.

8. The jib of a crane makes an angle of 51° with the perpendicular; its length is 18 feet; the stay rods are secured to the centre shaft 6 feet above the heel of the jib. Find the thrust on the jib and the strain on the stays when lifting a weight of 5 tons, neglecting the relief the stays get from the lifting chain. *Ans.*, 12·6 tons on stays, 15·4 tons thrust on jib.

CHAPTER X.

CALCULATION OF THE CROSS BREAKING STRAIN OF FIR SPARS.

Breaking Strain of Spars.—The formula for the cross breaking weight of timber is—

$$W = \frac{4\ b\ d^2\ S}{6 \times l}$$

where W is the breaking weight in pounds, l the distance between the points of support, b the horizontal breadth, d the vertical depth of the spar, all given in inches. S is a coefficent for fir timber, and is taken at 6600 = six times m given in Table 4, page 82. The safe working load may be taken as $\frac{1}{4}$W, when the spar has not been specially selected timber.

The formula may be verbally written:

Muttiply four times the breadth of the spar by the square of the depth when in use and by 6600, *divide the product by six times the length; the quotient will be the breaking strain of the spar in pounds. Divide the breaking strain by* 4 *for the safe working load.*

As square spars are most commonly used on board ship for weight-bearing purposes, their breadth is equal to their depth, when such is the case the rule may be written:

Multiply four times the cube of the spar's breadth by 6600 *and divide the product by six times the distance between the points of support; the result will be the breaking strain in pounds.*

The spar is supposed to be supported horizontally at both ends and loaded in the middle. But spars are not often used in this manner on board ship; nevertheless it gives an idea of the cross strain necessary to break a spar when it is being used as a derrick and shows a tendency to buckle.

In derricks the strain is a thrust or crushing strain along the axis of the spar, in which direction the resistance to crushing is very great; but sometimes with a swinging derrick, heeled at a great angle with a heavy weight hanging to it, the spar may be seen to buckle while the weight is being lowered by the tackle. A knowledge of the cross breaking strain of the spar when supported at the heel and at the point where the topping-lift is made fast will enable an estimate to be made as to whether or not the strain causing the spar to buckle is likely to break it. It is no security to a derrick to put what is called a belly-lashing round the middle of the derrick and the mast, because the derrick is just as likely to buckle upwards as downwards in the vertical plane, and if all the strains are not in the same vertical plane the spar may buckle sideways, as, for example, when the derrick is held amidships while the ship has a list during the process of heaving up or lowering a weight.

An example or two will illustrate the application of the rule for finding the cross breaking strain. A square spar of fir measures 16 inches by 16 inches section, and is 36 feet between the points of support; what will be the breaking strain when the spar is loaded at the middle?

$$\text{Breaking strain} = \frac{4 \times 16 \times 16^2 \times 6600}{432 \times 6} = 41718 \text{ lbs.}$$

$$= 18{\cdot}61 \text{ tons.}$$

And since the safe working load is $\frac{1}{4}$ breaking strain—

we get, $$\frac{18{\cdot}61}{4} = 4{\cdot}65 \text{ tons working load;}$$

this would be the safe load for the spar in a horizontal position, and is greatly in excess of the cross strain likely to affect it while acting as a derrick.

A spar measures 24 feet between the supports and is 12 inches by 12 inches square; what will be its breaking cross strain?

$$\text{Breaking strain} = \frac{4 \times 12 \times 144 \times 6600}{288 \times 6} = \frac{1728 \times 1100}{72}$$

$$= 26{,}400 \text{ lbs.} = 11{\cdot}8 \text{ tons.}$$

$$\text{Safe working load} = \frac{11{\cdot}8}{4} = 2{\cdot}95 \text{ tons.}$$

A piece of shafting weighing 16 tons has to be landed from a vessel in dry dock, across a stage 20 feet in length; what will be the necessary section of the spars required, supposing that two are used and that the whole weight of the shaft may rest on either one of them—

$$W = \frac{4b \times d^2 \times 6600}{240 \times 6}$$

but the spars being square in section $b = d$,

Therefore,

$$W = \frac{4d^3 \times 1100}{240}$$

Therefore,

$$d^3 = \frac{240W}{4400}$$

but W is the breaking strain and is four times the safe load. Therefore,

$$d^3 = \frac{240 \times 64 \times 2240}{4400}$$

$$= \frac{60 \times 64 \times 2240}{1100}$$

Therefore,

$$d = \sqrt[3]{7819{\cdot}7} = 19{\cdot}85 \text{ inches.}$$

That is, the spars would require to be 20 inches square for either one to bear the whole load safely.

In actual practice this would not happen, because the shaft would be hung in the tackles until it was landed, so that only a portion of the weight would at any time rest on the spars. However, we will now suppose that each spar has to bear half the weight of the shaft, and calculate their size—

$$d^3 = \frac{240 \times 32 \times 2240}{4400}$$

Therefore, reducing the fraction, we get—

$$d^3 = \frac{96 \times 448}{11}$$

Therefore,

$$d = \sqrt[3]{39098} = 15\tfrac{3}{4} \text{ inches.}$$

This is the size of the square spar whose cross breaking strain for the given length is 32 tons and the safe working load 8 tons.

This formula may be given in the following rule:

Multiply the distance between the points of support by four times the weight to be supported, and divide by 4400; *the cube root of the quotient will be the breadth of a square spar whose working load is the weight used.*

The cube root of a number is most easily found by taking the logarithm of the number and dividing it by 3; the resulting log will be the log of the cube root sought.

The foregoing formulæ are for rectangular spars only, therefore, when we want to find the cross breaking strain of a round spar, we have given the following equation for equal moments of area. Let D be the diameter of the round spar, ·7854 the multiplier for the area of a circle, B the breadth of the square spar—

Then,

$$\frac{\cdot 7854 \cdot D^3}{8} = \frac{B^3}{6}$$

Since for the square spar the cross breaking strain equals—

$$\frac{4 \times B^3 \times 6600}{6 \times l}$$

we will have for the round spar—

$$\text{Cross breaking strain} = \frac{4 \times \cdot 7854 \times D^3 \times 6600}{8 \times l}.$$

Hence for the cross breaking strain of a round spar, the rule is—

Multiply four times the cube of the diameter by ·7854 *and by* 6600, *which is the S in the first formula; and divide the product by eight times the length; the quotient will be the cross breaking strain of the spar* in lbs.

EXAMPLE I.—A round spar is 16 inches in diameter and is the top-mast of a ship; the distance between the cap and the eyes of the top-mast rigging is 20 feet; find the cross breaking strain at the middle of the mast.

$$\text{Breaking strain} = \frac{4\,D^3 \times \cdot 7854 \times 6600}{8 \times 240}$$

$$= \frac{4 \times 3217 \times 6600}{8 \times 240}$$

Reducing we get it—

$$= \frac{3217 \times 55}{4} = 44234 \text{ lbs.}$$

Therefore, cross breaking strain in tons—

$$= \frac{44234}{2240} = 19\cdot 7 \text{ tons.}$$

EXAMPLE II.—A fir top-mast is 12 inches in diameter and 16 feet from the cap to the eyes of the rigging, what will be its least breaking strain when the top-sail is dragging horizontally or at right angles to the axis of the spar?

Here the least breaking strain must be when the top-sail yard is at the middle of the mast.

$$\text{Breaking strain} = \frac{4 \times 12^3 \times \cdot 7854 \times 6600}{8 \times 192}.$$

$$= \frac{678\cdot 6 = 6600}{192}$$

$$= \frac{678{\cdot}6 \times 275}{8} = 23{,}327 \text{ lbs.}$$

Therefore, breaking strain in tons

$$= \frac{23{,}327}{2240} = 10{\cdot}4 \text{ tons.}$$

The safe working load would be, as in the square spars, one-fourth of the breaking strain.

Hence, in Example I., the safe load would be,

$$\frac{19{\cdot}7}{4} = 4{\cdot}9 \text{ tons,}$$

and in the last example

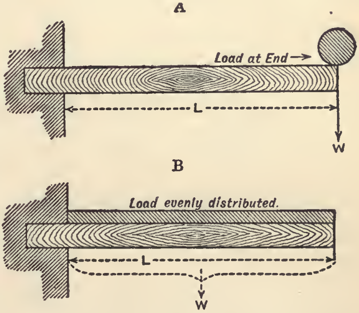
$$\frac{10{\cdot}4}{4} = 2{\cdot}6.$$

It must be remembered that in these calculations the measurements are all in inches and the weights in pounds, and that the coefficient S, = 6600, is six times the mean breaking weight of the timber called Mars-forest in the Table at page 82.

In the preceding examples the cross breaking strain of spars has been calculated for the load in the middle, which is the position at which a load produces the greatest strain on a beam or spar supported at both ends.

When the load is uniformly distributed over the spar between the points of support it will bear double the load it would at the middle. A ship's beams and yards are examples of uniformly distributed loads. The accompanying diagrams (Fig. 33) will show the manner in which spars may be loaded. The figures A and B show a spar supported at one end. In the case A the load is applied at the unsupported end, which suppose to be 1 ton and the length of the spar 6 feet; neglecting its own weight, the centre of gravity of the load is

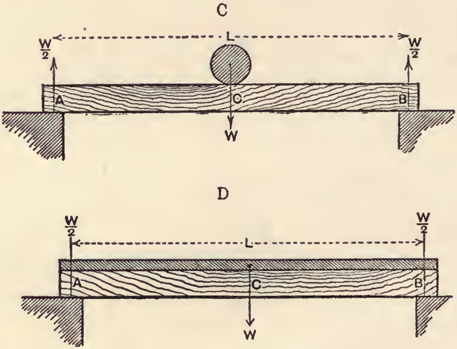
FIG. 33.



6 feet from the point of support; therefore the reaction at the point of support is equal to 1 ton × 6 = 6 tons. In the case B the load is uniformly distributed along the spar, therefore the centre of gravity of the load is at the middle, *i.e.*, 3 feet from the point of support; now in the case A the reaction at this point was 6 tons; therefore, since 6 ÷ 3 = 2, it would require 2 tons uniformly distributed along the spar to produce the same reaction at the point of support as 1 ton does at the end.

The next two cases (Fig. 34) show a spar supported at both ends. In the case C the load is at the middle of the spar, therefore the reaction of the supports at each end is equal to half the load on the spar; hence it will bear four times the strain that case A will support. Case D has the spar uniformly loaded, therefore each support bears half the weight, as in case C. But we may consider the load as acting at two points, each midway between the supports and the middle of the spar; these will each represent the centre of gravity of half the load, and taking the moments of these half loads, each round its nearest support, we get their sum equal to half the sum of the moments in case C; therefore its breaking strain or load must be double the load on C. Suppose in case C that the spar is 8 feet between the points of support and a weight of 1 ton is at the middle, the sum of its moments

FIG. 34.



will be $\frac{1}{2} \times 4 = 2$. In case D, the sum of the moments will be $\frac{1}{2} \times 4 - \frac{1}{2} \times 2 = 2 - 1 = 1$.

If we take the formula for finding the breaking strain of a spar supported and loaded as in case A, which is when the spar is Mars Forest timber,

$$\text{Breaking load} = \frac{\text{breadth} \times \text{depth}^2}{6 \times \text{length}} \times S;$$

Case B gives

$$\text{Breaking load} = 2\,\frac{\text{breadth} \times \text{depth}^2}{6 \times \text{length}} \times S;$$

Case C gives

$$\text{Breaking strain} = 4\,\frac{\text{breadth} \times \text{depth}^2}{6 \times \text{length}} \times S,$$

where $S = 6 \times m$,

Case E gives

$$\text{Breaking strain} = 8\,\frac{\text{breadth} \times \text{depth}}{6 \times \text{length}} \times S.$$

Therefore the relative strengths of the spars according to the manner of loading and supporting them are:

A = strength 1
B = „ 2
C = „ 4
D = „ 8

It will be seen by the formulæ just given that the strength of a rectangular spar is proportional to its breadth and to the square of its depth; that is, if the depth of a spar be doubled while its breadth remains unaltered its strength is increased four times. If the breadth is doubled while the depth remains unaltered the strength is also doubled. The strength of spars which are perfectly square in section varies as the cube of the side of the section. These are the proportions when the length of the spar remains the same; but when a spar of given section varies in length between the points of support, its strength is inversely proportional to its length—*i.e.*, as its length increases its strength decreases.

Table IV. gives the approximate mean breaking strain of rectangular spars or beams of various kinds of timber, 1 inch long and 1 square inch in section, supported at one end and loaded at the other. These values represent the multiplier m, given in the formulæ.

By calculation from the beam theory the constant S given in the formula page 75 is the ultimate compressing or tearing strength of the material in the direction of the length of the beam, and is six times the value of *m* given in Table IV.

TABLE IV.

Timber.	Mean Breaking Weight in Pounds.	Timber.	Mean Breaking Weight in Pounds.
Mahogany . .	1671	American fir .	1572
Ash . . .	2070	Mars Forest .	1100
Teak . . .	2460	Memel fir . .	1683
Oak . . .	1800	Riga fir . .	1371
Elm . . .	1215	Christiania .	1722
African oak .	2560	Pitch pine . .	1632

The strength of round spars varies as the cube of their diameter when they are of the same length. When of the same diameter their strength varies inversely as their length. Therefore we may say they vary in strength as the cube of their diameter directly and as their length inversely.

To find the strongest rectangular log that can be cut out of a round spar.—Divide the diameter by the square root of 3 for the breadth of the rectangular log, and to find the depth, multiply the diameter by the square root of 2, and divide by the square root of 3.

For example: A round spar is 20 inches in diameter; what are the dimensions of the strongest rectangular spar that may be cut out of it?

$$\text{The } \sqrt{2} = 1{\cdot}414,\ \sqrt{3} = 1{\cdot}732$$

$$\text{Breadth} = \frac{20}{1{\cdot}732} = 11{\cdot}55 \text{ inches.}$$

$$\text{Depth} = \frac{1{\cdot}414}{1{\cdot}732} \times 20 = {\cdot}816 \times 20 = 16{\cdot}32 \text{ inches.}$$

Dividing by the $\sqrt{3}$ is the same as multiplying by its reciprocal ·577, and the factor $\cdot 816 = \frac{\sqrt{2}}{\sqrt{3}}$

The proportion of the breadth to the depth would be

$$11{\cdot}55 : 16{\cdot}32 :: 5 : 7$$

The strength of a perfectly square spar cut out of a round one would be to that of the above rectangular spar in the proportion of 10 to 27, for the cube of the side of the square spar would be 1130·67; while the breadth of the rectangular spar, multiplied by the square of its depth, gives 3076·23.

Finding the Weight of Spars. *To find the weight of spars.*—First calculate their cubic contents, and then multiply by the weight per cubic foot found in Table V. of *specific gravities.*

The *specific gravity* of any substance is the proportion a cubic foot of it bears to a cubic foot of fresh water. Now, a cubic foot of fresh water weighs 1000 ounces, or $62\frac{1}{2}$ lbs.; its *specific gravity* is called 1·0, and to this standard all *specific gravities* refer. For example: Suppose, on referring to a table of specific gravities, we find the S. G. of Dantzic pine to be 0·65, then, to ascertain the weight of a cubic foot of it we have only to multiply 0·65 by 62·5 lbs. for the weight in lbs., thus:

$$62{\cdot}5 \times {\cdot}65 = 40{\cdot}625 \text{ lbs.}$$

To find the weight of a square or rectangular spar. Calculate the number of square feet or inches in the end section; multiply this area by the length in feet or inches; the product is the solid content in cubic feet or inches.

To find the weight: Multiply the content in cubic feet by the weight per cubic foot found in Table V. Or, multiply the content in cubic feet by the product of the specific gravity and 62·5 *lbs.*

EXAMPLE I.—Required the weight of a pitch pine spar, square in section, 15 in. × 15 in. × 40 feet.

Therefore, $1{\cdot}25 \times 1{\cdot}25 \times 40 = 62{\cdot}5$ cubic feet.

The specific gravity of pitch pine is, by Table V., = ·68, or the weight per cubic foot = 42·9 lbs.

Therefore, $62{\cdot}5 \times 42{\cdot}9 = 2681$ lbs. = 23 cwt. 3 qrs. 21 lbs.

EXAMPLE II.—A round spar is 15 inches in diameter and 40 feet long; find its weight.

The area of a circle is equal to the square of the diameter multiplied by ·7854; hence

Area of section = $(1{\cdot}25)^2 \times {\cdot}7854 = 1{\cdot}229$ feet.
Content = $1{\cdot}229 \times 40 = 49{\cdot}167$ cubic feet.
The weight per cubic foot = 42·9 lbs.

Therefore, $49{\cdot}167 \times 42{\cdot}9 = 2109{\cdot}26$ lbs.; weight of spar = 18 cwt. 3 qrs. 9 lbs.

TABLE V.—WEIGHTS AND SPECIFIC GRAVITIES.

Material.	Specific Gravity.	Weight per Cubic Foot.
		lbs.
Water, fresh	1·0	62½
„ sea	1·027	64
Iron, cast	7·23	451
„ wrought	7·78	485·6
Copper	8·75	549
Granite	2·63	164
Ash	·76	47
English elm	·54	34
Larch	·55	35
African oak	·98	62
English „	·77	48
Dantzic pine	·65	40·6
Memel „	·55	34
Oregon „	·60	37·8
Pitch „	·68	42·9
Red „	·57	36
Riga „	·65	41
Sabicu „	·96	60
African teak	·98	61
Indian „	·88	55
Mahogany	·56	35
Mercury	13·57	848·12
Ice	·93	58·1

When the spar tapers uniformly from heel to tip, find the sectional area for a point in the middle of the spar and call this the mean sectional area. But if the spar tapers from the middle towards each end, find the area of section at a point half-way between the middle and the end; this will be the mean sectional area, and in both cases multiply this area by the whole length of the spar for the cubic content.

Examples. EXAMPLE III.—Find the weight of a round Dantzic spar 53 feet in length, diameter of heel 15 inch, and of head 9 inches. Here the mean diameter is 12 inches, or 1 foot; therefore—

$$\text{Cubic content} = 1^2 \times \cdot 7854 \times 53 = 41\cdot 626 \text{ cubic feet.}$$

The specific gravity of Dantzic fir is ·65.

Therefore,

$$\text{Weight of spar} = 41\cdot 626 \times 62\cdot 5 \times \cdot 65 = 1689\cdot 22 \text{ lbs.}$$

Or since the weight of a cubic foot of Dantzic fir is 40·6 lbs.

Weight of spar = 41·626 × 40·6 = 1690 lbs.
= 15 cwt. 10 lbs.

Example IV.—A pitch pine top-mast is 38 feet in length and has a mean diameter of 14 inches, allowing the excess of wood in the heel to make up for what is cut away at the mast head.

Content of spar = $(1·17)^2$ × ·7854 × 38 = 40·86 cubic feet.
Weight of spar = 40·86 × 42·9 = 1753 lbs.
= 15 cwt. 2 qrs. 17 lbs.

Finding the Floating Power of Spars.—The floating power of a spar is the difference between the weight of a cubic foot of the spar and the weight of a cubic foot of water.

Find the number of cubic feet in the spar by the foregoing rules, multiply this by the difference between the weight of a cubic foot of the spar and the weight of a cubic foot of water; the product will be the number of pounds the spar will sustain in water.

Example I.—The top-mast in the preceding example contains, say, 51·68 cubic feet; find its floating power in sea water.

A cubic foot of pitch pine weighs 42·9 lbs. and a cubic foot of sea water weighs 64 lbs., therefore—

$$\left.\begin{array}{r}\text{Floating power}\\ \text{in sea water}\end{array}\right\} \begin{array}{l} = (64 - 42·9) \times 51·68 = 21·1 \times 51·68 \\ = 1090 \text{ lbs.} = 9 \text{ cwt. } 2 \text{ qrs. } 26 \text{ lbs.}\end{array}$$

Example II.—An anchor weighing 40 cwt. has to be tripped by means of a Spanish windlass rigged upon a raft of pitch pine; what quantity of wood will be required for the purpose, supposing it to consist of round spars 1 foot in diameter?

Here we have given the floating power, required to find the quantity of wood. Therefore we divide the floating power by the difference between the weight of a cubic foot of the wood and a cubic foot of sea water, which gives the number of cubic feet required—

40 cwt. = 4480 lbs. and 64 – 42·9 = 21·1

Therefore 4480 ÷ 21·1 = 212·3 cubic feet.

But the spars are round; we must therefore ascertain the content of a lineal foot of such spar and divide 212·3 by it to get the number of lineal feet required.

Content of a foot of spar = 1^2 × ·7854 × 1 = ·7854 cubic feet. Therefore 212·3 ÷ ·7854 × 270·3 feet in length of spar 1 foot in diameter required to merely sustain the weight of the anchor. Now suppose that with the weight of the chain and the strain of breaking out the anchor the raft had to support 2½ tons, then the number of feet of spar would have to be increased by a quarter of itself, which would be 270·3 + 67·5 = 337·8 feet of round spar, or 11 spars 33 feet each in length. A ship never carries such an equipment of spare spars, the operation is therefore impracticable, except in a timber-laden ship.

Floating Power of Casks and Tanks.—*Square half the sum of the head and bung diameters; multiply by the length, and by* ·02832; *the product will be the weight in lbs. which the cask will float;* but if the cask contains any substance of a less specific gravity than sea water, the floating power will be equal to its content in gallons multiplied by the difference between the weight of a gallon of the substance and a gallon of sea water. The weight of the cask itself may be neglected in practice, as it is inappreciable. If tanks are employed for floating purposes they require to be strongly stayed inside—otherwise they will collapse—which stays are best made of wood; the weight of the tank itself must be deducted from the floating power given by its cubic measurement.

Before proceeding with any examples on the floating power of casks we must know *how to find the contents of a cask in gallons.*

Square half the sum of the head and bung diameters; multiply this by the length, and by ·002832; *the result will be the contents in gallons nearly.*

It will be observed that this is nearly a repetition of the rule for the floating power, excepting only that in the first rule the multiplier ·002832 is multiplied by 10, since a gallon of water weighs 10 lbs.; hence the floating power of an empty cask is merely its content in gallons multiplied by 10. Sea water is slightly heavier than fresh water, being about 10 lbs. 3 oz. to the gallon, but neglecting the difference gives a margin on the side of buoyancy.

A 36-gallon cask will float 36 × 10 = 360 lbs.

A hogshead, 63 gallons, will float 630 lbs., and so on.

The contents of casks in gallons being usually known, the floating power is at once known in lbs. by annexing a cypher to the gallons.

For the floating power of tanks, multiply the contents in cubic feet by ·571, *the result will be the floating power of the tank in salt water in hundredweights, from which deduct weight of the tank.*

Example III.—A tank measures 4 feet each way, *i.e.*, 4 × 4 × 4; what is its floating power when it weighs 6·8 cwt. empty?

4 × 4 × 4 = 64 cubic feet.

Floating power of 64 cubic feet = 64 × ·571 = 36·54 cwts.
„ tank = 36·54 − 6·8 = 29·74 „

Example IV.—Twelve baulks of pitch pine, each 32 feet in length and 16 inches square, are used to construct a raft. Find what weight they will float.

Cubic content of one baulk = 1·33 × 1·33 × 32 = 56·6 feet.
Floating power of one „ = 56·6 × 21·1 = 1194·3 lbs.
„ twelve „ = 1194·3 × 12 = 14331·6 lbs.

$$\text{Floating power in tons} = \frac{14331{\cdot}6}{2240} = 6 \text{ tons } 8 \text{ cwt.}$$

Floating Power of a Raft. Example V.—Six round spars, 30 feet in length and 10 inches in diameter, together with six casks of 36 gallons capacity (empty), are used to construct a raft. What will be its floating power, the spars being Dantzic pine?

Sectional area of a spar = 10 × 10 × ·7854 = 78·54 square inches.

$$\frac{78{\cdot}54}{144} = 0{\cdot}545 \text{ square foot.}$$

Content of spar = 0·545 × 30 = 16·35 cubic feet.
Content of the six spars = 16·35 × 6 = 98·1 cubic feet.
Weight of a cubic foot of Dantzic pine = 40·6 lbs.

Therefore, the floating power of spars (64 − 40·6) × 98·1 = 23·4 × 98·1 = 2295·54 lbs. = 1 ton 56 lbs.

Each cask will float 36 × 10 = 360 lbs.

Floating power of six casks = 2160 = 19 cwt. 32 lbs.

Adding these results we get	1 ton	0 cwt.	2 qrs.	0 lbs.
	0 „	19 „	1 „	4 „
Total	1 ton	19 cwt.	3 qrs.	4 lbs.

Reckoning 15 adults to the ton, this raft would be capable of sustaining the weight of 30 persons.

TABLE VI.—THE PROPERTIES OF BODIES.

Names of Bodies.	Specific Gravities.	Weight in lbs. of a Square Inch Bar 1 Foot long.	Weight in lbs. of a Cubic Foot.	Bears in lbs. on a Square Inch without permanent Alteration.	Tensile Strength in lbs. per Square Inch.	Crushed by a Force in lbs. on a Square Inch.	Absorbs of its Weight of Water.	Melts at Fahrenheit.
Air	0·0013	0·00056	0·0807	—	—	—	—	—
Ash	0·74	0·33	47·5	3796	16000	—	—	—
Beech	0·696	0·315	45·3	3113	11000	—	—	—
Bismuth, cast . .	0·822	4·26	614	—	—	—	—	476°
Brass, cast . . .	8·37	3·63	523	6700	18000	—	—	1869°
Brick	1·841	0·8	115	—	275	562	1·15	—
Clay	2	0·868	125	—	—	—	—	—
Coal, Newcastle . .	1·269	0·516	79·31	—	—	—	—	—
Copper	8·75	3·81	549	10000	33000	—	—	1950°
Elm, English . . .	0·544	0·236	34	3240	13000	—	—	—
Fir, red or yellow . .	0·557	0·242	34·8	4290	12000	—	—	—
Fir, white . . .	0·47	0·204	29·3	3630	—	—	—	—
Gold, pure . . .	19·351	8·4	1210·06	—	—	—	—	2100°
Granite, Aberdeen . .	2·625	1·138	164	—	—	10910	—	—
Gun-metal, cast . .	8·153	3·54	509·5	10000	34000	—	—	—
Iron, cast . . .	7·2	3·2	450	15300	16400	93000	—	2200°
Iron, wrought . .	7·6	3·3	475	17800	49280	—	—	3000°
Larch fir	0·560	0·243	35	2486	—	—	—	—
Lead	11·35	4·94	709·5	1500	—	—	—	617°
Mahogany . . .	0·56	0·213	35	3694	21000	8000	—	—
Marble, white. . .	2·7	1·17	169	4900	1811	6060	—	—
Mercury	13·568	5·888	348	—	—	—	—	39°
Oak, English . . .	0·83	0·36	52	3960	10000	—	—	—
Pine, American, yellow .	0·46	0·186	26·75	3900	—	—	—	—
Silver	10·474	4·54	654·62	—	—	—	—	1873°
Steel, cast . . .	7·84	3·4	490	40000	116480	—	—	—
Stone, Bath . . .	1·975	0·85	123·4	—	478	—	1·13	—
Stone, Craigleith . .	2·362	1·02	147·6	—	453	5287	1·63	—
Stone, Dundee . .	2·621	1.13	163·8	—	2661	6630	1·511	—
Stone, Portland . .	2·113	0·92	132	1500	857	3729	1·16	—
Tin, cast	7·291	3·165	455·7	2880	—	—	—	442°
Water, river . . .	1	0·434	62·5	—	—	—	—	—
Water, sea . . .	1·0271	0·445	64·2	—	—	—	—	—
Whalebone . . .	1·3	0·562	81	5600	—	—	—	—
Zinc, cast . . .	7·028	3·05	439·25	5700	—	—	—	736°

CHAPTER XI.

CENTRE OF EFFORT OF SAILS.

The centre of effort of a sail is that point in the sail at which, if the whole wind-force distributed over its surface were applied, it would produce the same effect, and corresponds with the centre of gravity of a plane surface. In the chapter on Centre of Gravity we dealt with weights, and the *moments* of weights; but in dealing with sails the pressures acting upon them are variable and unknown, while their areas are constant and known; we shall therefore deal here with areas and the *moments* of areas, called *areal moments.* As was explained in the article on the lever, the *moment* of a force is the product of that force into its distance from a fixed point (usually the fulcrum). Therefore the product of an area into its distance from a fixed point is its *areal moment* relative to that point, which, in this case, will be the stern-post for the fore and aft distances, and the deck for the vertical distances.

In finding the *centre of effort* of a ship's sails we shall only deal with the inner jib, spanker, top-gallant-sails, top-sails, and courses, neglecting all the stay-sails. For the fore and aft distances of the centres of effort of the square sails we will assume the distance between the stern-post and the centre of the lower masts at the *partners,* and consider the centre of effort of each square sail to be situated on a vertical line through this point for each mast.

To find the centre of effort of the jib, take a point in the middle of the foot—upon a scale plan of the sails—through this point and the angle at the head draw a line; next, from the middle of the after leach draw a line through the angle at the tack; the intersection of these two lines will be the centre of effort of the jib; measure the distance of this point from the stern-post, and its height above the deck for the horizontal and vertical centres of effort respectively.

To find the centre of effort of a spanker.—Divide it into two triangles by drawing a line from throat to clew; find the centre of effort of each triangle and join them by a line. Next draw a line from the head out-haul cringle to the tack; this, again, divides the sail into two triangles. Find the centre of effort of each and join them by a line; where this line cuts the line joining the centres of effort of the first two triangles is the centre of effort of the whole sail. Measure its distance forward of the stern-post and its height above the main deck for its horizontal and vertical centre of effort. If the spanker is a triangular one, bisect the foot and the after leach; from these points draw lines through their opposite angles; where these lines cut will be the centre of effort of the whole sail; or, draw a line through the middle of the foot and the head cringle, and the centre of effort will be one-third the length of this line above the foot.

To find the centre of effort of a square sail. Draw a vertical line down the middle of the sail, and divide the sail into two triangles by drawing a line from the starboard earing to the port clew; find the centre of effort of each of these triangles, and join them by a line; where this line cuts the vertical midship line is the centre of effort of the whole sail. Measure the height of this point above the deck for the vertical centre of effort, and proceed thus for every sail intended to be considered.

Areas of Sails.—We must next proceed to find the area of each sail, and beginning with the fore and aft sails, we will first take the jib.

From the clew of the jib draw a line perpendicular to the luff, multiply the length of this line by half the length of the luff for the area in square feet.

For the area of the spanker draw a diagonal line from the throat to the clew; from the head cringle, and from the tack draw lines perpendicular to this diagonal; multiply the length of the diagonal line by half the sum of the two lines perpendicular to it. The product will be the area of the spanker in square feet.

If the spanker is a triangular one, draw a line from the tack perpendicular to the after leach; multiply the length of this perpendicular by half the length of the after leach. The product will be the area in square feet.

To find the vertical moments of the sails.—Multiply the area of each sail into the height of its centre of effort above the deck; do this for each sail separately, add together the moments of the sails on each mast and divide the sum by the sum of the areas of the square sails on each mast; the result will be the position of the centre of effort above the deck for the whole square sail on each mast. Multiply the area of the jib into the vertical height of its centre of effort above the deck for its vertical moment and proceed in the same way for the vertical moment of the spanker.

Add together the vertical moments of the jib spanker and the total moments for each mast, divide this sum by the sum of all the areas of the sails; the result will be the vertical centre of effort for the whole sail on the ship.

For the fore and aft distance of the centre of effort of the whole sail from the stern-post.—Multiply the areas of the jib and spanker into their fore and aft distances from the stern-post, also multiply the total square sail area on each mast into the distance of the mast from the stern-post; these products will be the horizontal or fore and aft moments. Add together all these moments and divide the sum by the total sail area on the ship; the result will be the distance of the centre of effort of the whole sail from the stern-post. This fixes the position of the point at which, if the whole of the forces distributed over the surfaces of the ship's sails were applied, it would produce the same effect in propelling, turning, and heeling her.

Instead of finding the centre of effort for the whole sail of the ship, we may take for a point of reference the middle of the fore and aft length of the ship instead of the stern-post, and calling those sail efforts forward of this point *plus,* and those abaft *minus,* find the ratio of the forward to the after forces of the sails. When the position of the centre of gravity of the ship and cargo is known, these *plus* and *minus* moments may be referred to it, as it is round the centre of gravity that the ship turns and heels as a fulcrum. However, as has been shown, the centre of effort of the whole sail may always be found with reference to either the ship's half length point or to the stern-post, which by an easy transformation can be referred to the centre of gravity of ship and cargo when it becomes known, and hence the length of the turning arm of the lever is known as also the length of the heeling arm. By such an analysis the whole of the distributed forces acting upon the sails of a ship are reduced to their simplest elements, and the ship becomes a lever of the first kind, with her centre of gravity for a fulcrum and the wind pressure upon the sails for the *power* and *resistance.*

Stable Motion.—A ship by the wind may be considered as a lever in equilibrium under the distributed action of her sails, and when the disposition of these is perfect the ship might steer herself could she remain upright. In practice, however, she heels over and disturbs the balance of the sails by griping, and requires the aid of the helm to restore the equilibrium by carrying it aweather, to keep the ship out of the wind. The cause of the griping will be explained in the article on pressure of water on the lee bow.

Since we learn from the foregoing investigation that the centres of effort of the sails on each mast are all situated in the same vertical fore and aft plane which passes through the ship's centre of gravity and keel when she is upright, it is evident that, with one exception only, the propelling force of the wind is always inclined to this plane, which, with slight assistance from the helm, secures stability in the ship's direction of motion.

Unstable Motion.—When a ship is running with the wind right aft, then are the centre of gravity of the ship, the centre of effort of all the sails, the direction of the wind's propelling force, and the direction of the ship's motion all situated in the same vertical fore and aft plane passing through the ship's keel. Hence her condition is one of instability respecting her direction of motion. She therefore yaws about and steers wildly, and the yards being square there is no counteracting force to her heavy rolling in a sea way, and the rolling increases the yawing by the alternating immersion of the bows, which thrusts first one bow and then the other out of the line of motion, which the helm is almost powerless to counteract in time to keep the ship straight on her course. Hence the great difficulty experienced in steering a ship running, especially a short vessel.

A ship running dead before the wind with yards squared may be likened to a stick projected or thrown in the direction of its own length, whose motion is one of instability owing to the slightest disturbance acting upon it being capable of causing it to whirl round its centre of gravity in any plane whatever. The arrow is a familiar example of a stick projected in the direction of its own length, but it is steered straight through the air by being weighted by the barb or shoe at the head and feathered at the tail. This feather performs the same part for the arrow that the rudder does for the ship.

The difference between the ship running and the unbalanced stick thrown in the direction of its own length is, that the ship only yaws about her centre of gravity in a horizontal plane, while the stick is free to whirl round its centre of gravity in any plane whatever—*i.e.*, it may whirl round its centre of gravity in a vertical or horizontal plane or in a plane inclined at any angle to either of these planes.

Example of a Modern Ship.—We will now give a worked example of finding the centre of effort of a ship's sails. The dimensions are taken from a sail plan of a four-masted steel barque.

The registered dimensions are: Length, 312·9; breadth, 48·15; depth, 25·0; and length of load line 298 feet; gross tonnage, 2842·44; net tonnage, 2567·52.* The positions of the masts and yards are given in a table. The calculation will be most conveniently performed by means of another table drawn up in the following form. The first column contains the names of the sails, the 2nd, 3rd and 4th, the *head, foot,* and *depth* measurements of the sails. Multiply half the sum of the head and foot measurements by the depth, this gives the areas of the sails in square feet, which fill into column 5; in column 6 enter the heights of the centres of gravity, or, which is the same thing, the *centres of effort* of the sails above the deck; call these the vertical *centres of effort.*

Table of Calculation.—Multiply the areas in column 5 by the vertical C.E.'s in column 6; this gives the vertical moments; in column 8 write down the distance of the centre of the mast at the level of the deck from the stern-post; this is the horizontal centre of effort. When the areas and vertical moments for all the square sails on the fore-mast have been found, add all the moments together and all the areas together; divide the sum of the moments by the sum of the areas, this gives the vertical centre of effort for all the square sails on the fore-mast, which enter in column 10. Multiply the sum of the areas in column 5 by the horizontal C.E. in column 8, this gives the horizontal moment referred to the stern-post, which write in column 9. Since the measurements for finding the area of the jib are the distance from luff to clew and the length of the luff, enter these under those headings in columns 2, 3, and 4, and the areas and moments in their respective columns; then proceed with the sails on the main-mast and mizen-mast, as was done for the fore-mast. The measurements for finding the area of the spanker are the distance from the after leach to the tack and the length of the after leach; these are inserted in columns 2, 3, and 4, under their special headings.

The measurements for the depth of the square sails have been taken from the top of the yard to half-way between the foot and the next yard to allow for the roach in the foot of the sail, but excepting the lower top-gallant-sails and top-sails the other sails are practically straight on the foot. The following table contains the distances of the masts from the stern-post and the heights of the yards above the deck, taken from the sail plan.

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* The ship in question was built by Messrs. Robert Duncan & Co., Port Glasgow, who kindly furnished the plan for insertion here.

TABLE VII.

<table>
<tr><th colspan="4">FORE-MAST.</th><th colspan="4">MAIN-MAST,</th></tr>
<tr><th>Yards.</th><th>Height above deck.</th><th>Dist. of Mast from Stern-post.</th><th>Centre of Effort below Yard.</th><th>Yards.</th><th>Height above deck.</th><th>Dist. of Mast from Stern-post.</th><th>Centre of Effort below Yard.</th></tr>
<tr><td></td><td>Feet.</td><td>Feet.</td><td>Feet.</td><td></td><td>Feet.</td><td>Feet.</td><td>Feet.</td></tr>
<tr><td>U.T.G.</td><td>140</td><td></td><td>10</td><td>U.T.G.</td><td>142</td><td></td><td>10</td></tr>
<tr><td>L.T.G.</td><td>121</td><td></td><td>10</td><td>L.T.G.</td><td>123</td><td></td><td>10</td></tr>
<tr><td>U. Topsail</td><td>101</td><td>253</td><td>13</td><td>U. Topsail</td><td>104</td><td>174</td><td>14</td></tr>
<tr><td>L. Topsail</td><td>76</td><td></td><td>11·5</td><td>L. Topsail</td><td>78</td><td></td><td>11·5</td></tr>
<tr><td>Fore</td><td>52</td><td></td><td>20</td><td>Main</td><td>53</td><td></td><td>21</td></tr>
<tr><th colspan="4">MIZEN-MAST.</th><th colspan="4">JIGGER-MAST.</th></tr>
<tr><td rowspan="4">U.T.G.
L.T.G.
U. Topsail
L. Topsail
Crossjack</td><td rowspan="4">142
123
104
78
53</td><td rowspan="4">98</td><td rowspan="4">10
10
14
11·5
21</td><td>Sail.</td><td>V.C.E.</td><td>Hor.C.E.</td><td></td></tr>
<tr><td>Spanker</td><td>50</td><td>10</td><td></td></tr>
<tr><th colspan="4">JIB-BOOM.</th></tr>
<tr><td>Jib</td><td>40</td><td>311</td><td></td></tr>
</table>

SAILS ON FORE-MAST.

1	2	3	4	5	6	7	8	9	10
Sail.	Measurement.			Areas in Sq. Feet.	Vertical C.E.	Vertical Moments.	Horizontal C.E.	Horizontal Moments.	Vertical C.E. for total Sail on each Mast
	Head.	Foot.	Depth.						
	Ft.	Ft.	Ft.	Ft.	Ft.	Products of cols. 5 and 6.	Ft.	Products of cols. 8 and 5.	Ft.
U. T. G. sail	60	71	18	1179	130	153270			
L. „ „	69	78	18	1323	111	146853			
U. topsail .	75	88	25	2037	88	179256	253	2606153	70·75
L. „ . .	86	96	22	2002	64·5	129129			
Foresail . .	92	96	40	3760	32	120320			
				10301		728828			
	Luff.	Luff to clew.							
Jib. . . .	78	25		975	40	39000	311	303225	40
SAILS ON MAIN-MAST.									
U. T. G. sail	60	71	18	1179	132	155628			
L. „ „	69	78	18	1323	113	149499			
U. topsail .	75	88	26	2119	90	190710	174	1839354	71·45
L. „ . .	86	96	22	2002	66·5	133133			
Mainsail . .	92	96	42	3948	32	126336			
				10571		755306			
SAILS ON MIZEN-MAST.									
U. T. G. sail	60	71	18	1179	132	155628			
L. „ „	69	78	18	1323	113	149499			
U. topsail. .	75	88	25	2037	90	183330	98	1027922	70·75
L. „ . .	86	96	22	2002	66·5	133133			
Crossjack . .	92	96	42	3948	32	126336			
				10489		747926			
SAILS ON JIGGER-MAST.									
	After leach	After leach to tack.							
Spanker . .	100	44		2200	50	110000	10	22000	50
								5798654	

It will be seen from the table that the centre of effort for the square sails on each mast is about the same height above the deck, and is situated in the lower top-sail; but the vertical centre of effort for the whole sail on the ship will be somewhat lower than these, owing to the centres of effort of the jib and spanker being only 40 and 50 feet respectively above the deck.

To find the vertical centre of effort of the whole sail we sum up all the areas and all the vertical moments, and divide the sum of the moments by the sum of the areas; the result will be the vertical centre of effort for the whole of the sails, thus:

	Column 5. Areas.	Column 7. Vertical Moments.
Fore-mast	10301	728828
Main „	10571	755306
Mizen „	10571	747926
Jib „	975	39000
Spanker	2200	110000
Sum	34536	2381060

```
34536)2381060(68·94
      207216
      ------
       308900
       276288
       ------
        326120
        310824
        ------
         152960
         138144
         ------
          14816
```

68·94 feet is the height of the centre of effort of the whole sail of the ship above the deck.

We next sum up all the horizontal moments in column 9 and divide by the sum of the areas in column 5; this gives the horizontal distance of the centre of effort of the whole of the sail from the stern-post.

The sum of the moments in column 9 gives the whole of the horizontal moments.

Therefore,

$$\text{Horizontal centre of effort} = \frac{5798654}{34536} = 168 \text{ feet nearly.}$$

That is, the horizontal position of the centre of effort of all the sails is 168 feet forward of the stern-post.

The length of the ship from stern-post to stem at the load-water-line is 298 feet; therefore the middle point of this length is 149 feet forward of the stern-post; hence the centre of effort relative to this point is 19 feet forward of it.

By adopting the middle point of the length of the load-water-line as a point of reference instead of the stern-post we may calculate the moments of the sails forward of and abaft this point, by which we can ascertain the ratio of the forces forward to the forces abaft the middle point of the ship's load-water-line as a fulcrum.

	Hor. C.E.s from Sternpost. Ft.		Mid-point. Ft.		C.E. from Mid-point. Ft.	
Jib . .	311	−	149	=	+162	forward
Fore-mast .	253	−	149	=	+104	„
Main- „ .	174	−	149	=	+ 25	„
Mizen-„ .	98	−	149	=	− 51	abaft
Spanker .	10	−	149	=	−139	„

If we now multiply these horizontal centres of effort into the areas of the sails at these points we get the forward and after moments:

Sails.	Areas. Sq. Ft.		Hor. C.E. Ft.		Hor. Moments.	Sum.
Jib . . .	975	×	+ 162	=	+ 157950	1493529
Fore-mast .	10301	×	+ 104	=	+1071304	
Main- „ . .	10571	×	+ 25	=	+ 264275	
Mizen-„ . .	10489	×	− 51	=	− 534939	840739
Spanker . .	2200	×	− 139	=	− 305800	

Therefore the pressure of the sail forward of the middle point of the ship's load-water-line is to the pressure of the sail abaft this point as:

1493529 to 840739,

therefore the ratio of the forward to the after pressures or forces,

$$840739 \div 1493529 = 0{\cdot}563$$

That is, the forward force is to the after force as 1 is to 0·563.

When the horizontal position of the centre of gravity of the ship is given by the builder the difference between it and horizontal centre of effort of the sails will be the length of the turning arm, and the difference between the vertical position of the ship's centre of gravity and the vertical centre of effort of the sails will be the length of the heeling arm.

We give here another example of a four-masted steel barque, built by Messrs. Robert Duncan and Co., Port Glasgow. Her registered dimensions are: length, 282·05 feet; breadth, 42·85 feet; depth, 24·7 feet; tons, 2307·32 gross; 2146·58 net; 3800 tons dead weight.

This ship carries no sail above the top-gallant-sails, and the following table gives the positions of the masts from the sternpost, and the height of the yards above the deck when the sails are set, also the distance of the centre of effort of each square sail below its yard, taken from a scale drawing of the ship.

TABLE VIII.

FORE-MAST.				MAIN-MAST.			
Yards.	Height above deck.	Mast's Dist. from Stern-post.	Centre of Effort below Yard.	Yards.	Height above deck.	Mast's Dist. from Stern-post.	Centre of Effort below Yard.
	Ft.	Ft.	Ft.		Ft.	Ft.	Ft.
U.T.G.	136		13	U.T.G.	138		13
L.T.G.	112		11	L.T.G.	113		11
U. topsail	89	226	13	U. topsail	90	163	13
L. topsail	63		10	L. topsail	64		10
Foresail	41		15	Mainsail	43		16
MIZEN-MAST.				JIGGER-MAST.			
U.T.G.	138		13	Sail.	V.C.E.	Hor.C.E,	
L.T.G.	114		11				
U. topsail	91	94	13				
L. topsail	65		10	Spanker	48	16	
Crossjack	43		16				
				JIB-BOOM.			
				Jib	35	269	

We now arrange all our data in a tabular form, similar to that of the last example, and proceed with the calculation.

SAILS ON FOREMAST.

1	2	3	4	5	6	7	8	9	10
Sails.	Measurements.			Areas in Sq. Feet.	Vertical C. E.	Vertical Moments.	Horizontal C.E.	Horizontal Moments.	Vertical C.E. for total Sail on each Mast.
	Head.	Foot.	Depth.						
	Ft.	Ft.	Ft.	Ft.	Ft.	Products cols. 5 and 6.	Ft.	Products cols. 5 and 8.	Ft.
U.T.G. . .	57	65	24	1464	123	180072			
L. „ . .	64	73	21·5	1473	101	148773			
U. topsail . .	70	81	25	1887	76	143412	226	1977726	70·4
L. „ . .	79	84	19	1549	53	82097			
Foresail . .	80	84	29	2378	26	61828			
				8751		616182			
	Luff.	Luff to clew.							
Jib	69	20		600	35	21000	269	161400	
SAILS ON MAIN-MAST.									
U.T.G. . .	56	65	24	1452	125	181500			
L. „ . .	64	73	21	1438	102	146676			
U. topsail . .	70	81	25	1887	77	145299	163	1470586	69·79
L. „ . .	78	84	19	1539	54	83106			
Mainsail . .	80	84	33	2706	27	73062			
				9022		629643			
SAILS ON MIZEN-MAST.									
U.T.G. . .	56	65	24	1452	125	181500			
L. „ . . .	64	73	20	1370	103	141110			
U. topsail . .	70	79	25	1863	78	145314	94	836130	70·16
L. „ . .	77	83	19	1520	55	83600			
Crossjack . .	80	83	33	2690	27	72638			
				8895		624154			
SAIL ON JIGGER-MAST.									
	After leach.	Tack to after leach.							
Spanker . .	96	41		1968	48	94464	16	31488	48·0
							Sum	4477330	

To find the vertical position of the centre of effort of the whole sail above the deck, sum up all the areas in column 5, and all the vertical moments in column 7; then divide the sum of column 7 by the sum of column 5; the result will be the vertical height of the centre of effort above the deck.

	COLUMN 5. AREAS.	COLUMN 7. VERTICAL MOMENTS.
Fore-mast	8751	616182
Main- „	9022	629643
Mizen-„	8895	624154
Jib	600	21000
Spanker	1968	94464
	29236	1985443

29236)1985443(67·9 feet, nearly.
175416
231283
204652
266310
263124

Therefore the vertical centre of effort for the whole of the sails is 68 feet (nearly) above the deck.

Next sum up the horizontal moments in column 9 and divide by the sum of areas in column 5; the result will be the distance in a horizontal direction from the sternpost of the centre of effort of the whole of the sails.

Thus,

Col. 5 areas.	Col. 9 horizontal moments.
29236	4477330

Therefore,

$$4477330 \div 29236 = 153{\cdot}14 \text{ feet.}$$

That is, the horizontal centre of effort of the whole of the sails is 153·14 feet forward of the stern-post.

In this ship the length of the load-water-line is 269·08 feet, we therefore find the centre of effort to be 18·6 feet forward of the middle point of the length of her load-water-line.

The foregoing calculations are not more tedious than a day's work when the ship has been standing on short tacks during the twenty-four hours; and when provided with a scale-plan of the ship and sails the operation becomes quite simple and, when once executed, is a constant standard for reference to the varying position of the ship's centre of gravity, under different conditions of trim and disposition of cargo, whereby the seaman will be enabled to give expression to his experiences of the ship's handiness in manœuvring and standing up under press of sail, by stating the quantitative relation of the position of the ship's centre of gravity to the position of the centre of effort of the sails.

A very good idea of the position of the centre of effort of the sails may be obtained in a simple and expeditious way by the following approximate method:

Approximate Area of Square Sail. *To find approximately the area of the whole square sail on a mast.*—Add together the foot of the *course* and the head of the top-gallant-sail; take half the sum and multiply it by the height of the head of the top-gallant-sail above the foot of the *course.*

For example: In the first ship the head of the upper fore top-gallant-sail is 140 feet above the deck, and the foot of the fore-sail is 12 feet above the deck; the head of the top-gallant-sail measures 60 feet, and the foot of the fore-sail 96 feet.

$$\text{Therefore, } \frac{60 + 96}{2} = 78 \text{ feet.}$$

And $140 - 12 = 128$ feet, the distance from the foot of the foresail to the head of the top-gallant-sail.

Therefore,

The area of the whole sail $= 128 \times 78 = 9984$ square feet approximately, differing from the tabular area by about 35 square yards.

For the sails on the mainmast we get the head of the top-gallant-sail 142 feet above the deck, and foot of the main-sail 11 feet above the deck. The measurements for the head of the top-gallant-sail and foot of the main-sail are the same as fore-mast measurements,

$$142 - 11 = 131 \text{ feet,}$$

the distance between the foot of the main-sail and the head of the top-gallant-sail.

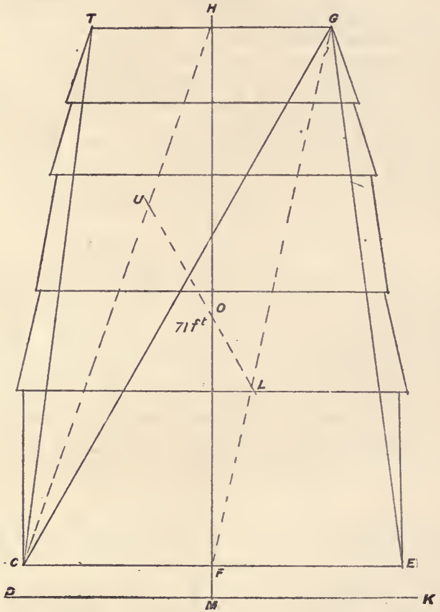
Therefore, approximately,

$$\text{Area of the whole sail} = 131 \times 78 = 10218 \text{ square feet,}$$

which differs from the tabular area by about 39 square yards.

Approximate Centre of Effort. *To find the approximate centre of effort of the whole square sail upon a mast.*—Draw a horizontal line DK (Fig. 35) to represent the deck; from the middle of DK erect a perpendicular MH to represent the mast. Make MH equal to the height of the head of the top-gallant-sail. Through H draw a horizontal line TG, equal in length to the head of the top-gallant sail. From M lay off MF on the mast equal to the height of the foot of the course above the deck, and through F draw the horizontal line CE, equal in length to the foot of the *course;* join TC and GE; the trapezoid TGEC represents approximately the area of the whole square sail on the mast. Divide the figure into two

FIG. 35.



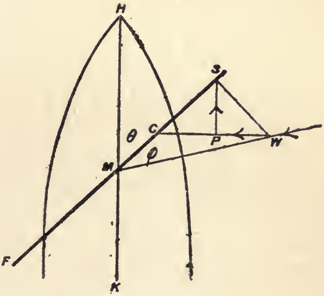
triangles by drawing a line from G to C; join FG; from F lay off one-third the distance FG equal to FL; L is therefore the centre of gravity of the triangle CGE. In the triangle TGC join HC. Make HU equal to one-third the distance HC; then U is the centre of gravity of the triangle TGC; join L and U; where the joining-line cuts the mast in O is the centre of effort of the whole square sail on the mast, and MO is its height above the deck.

In the diagram let MH = 140 feet.
MF = 12 „
TG = 60 „
CE = 96 „

From which we get MO = 72 feet, the height of the centre of effort of the whole square sail on the mast, which differs from the calculated centre of effort in the table for the first ship by 15 inches; the calculated value being $70\frac{3}{4}$ feet and the approximate 72 feet. This is a very ready method of finding the vertical centre of effort for the square sail on each mast, and may be executed in a few minutes. The same diagram will also do for the total area.

Propelling Component of the Wind.—Except when the wind is aft the whole of the wind force is not effective in propelling the ship in the direction of her keel, for it blows obliquely into the sails, and has therefore to be resolved into its components acting in specified directions to determine what portion of the wind force drives the ship ahead, and what portion drives the ship to leeward, or at right angles to her keel, the latter attaining its greatest value when a ship is close hauled or by the wind. We will therefore consider a ship under this condition and ascertain what percentage of the total wind force is effective in propelling the ship ahead. It will only be necessary to deal with one sail, as that will be sufficient to represent the propelling and leeway making components of the total wind force. We will represent in the diagram by a straight line the inclination of the surface of the sail to the ship's keel, considering this surface to be perfectly flat instead of bellied, as it really is, since the inquiry will be much simplified by thus dealing with it.

FIG. 36.



Let KH represent the ship's keel, FS the fore yard, HMS the angle which the supposed flat surface of the sail makes with the keel, WM the direction and magnitude of the wind force, and WMS the angle which the wind makes with the surface of the sail; draw WS perpendicular to SM, then WS represents the effective force of the wind on the sail, and SM the other component, which glides along the sail's surface and produces no effect. WS must be resolved into two components acting at right angles to each other, one of which is parallel to the keel, and the other at right angles to it; draw WC at right angles to the keel, and SP parallel to the keel; then SP represents the force which propels the ship, and WP the force which produces leeway. The angle WSC is a right angle and SP is parallel to HM; therefore the angle HMS is equal to the angle PSC; but the angles PSC and WSP are together equal to a right angle, and since SPW is a right angle, the angles WSP and PWS are also equal to a right angle; from each of these right angles take the angle WSP, and we get the angle PSC equal to the angle PWS, which is equal to the angle which the surface of the sail makes with the keel.

We may now find a rule for calculating these components. Let θ be the angle PWS, and ϕ the angle WMS; then:

$$\text{WS} = \text{MW sin. } \phi$$

$$\text{SP} = \text{WS sin. } \theta$$

Substituting for WS its value in the first equation,

we get $$\text{SP} = \text{MW sin } \phi \text{ sin. } \theta \qquad (1)$$

This gives the propelling component of the wind force.

$$\text{PW} = \text{WS cos. } \theta$$

Therefore $$\text{PW} = \text{MW sin. } \phi \text{ cos. } \theta \qquad (2)$$

This gives the leeway force component of the wind.

These two rules may be stated as follows:

To find the propelling force of the wind,

Multiply the force of the wind by the sine of the angle the wind makes with the sail and by the sine of the angle the sail makes with the keel.

To find the leeway force of the wind,

Multiply the force of the wind by the sine of the angle the wind makes with the sail and by the cosine of the angle the sail makes with the keel.

Example I.—A ship's yards are braced up making an angle of three points with the keel or fore and aft line, and the wind makes an angle of 2 points with the surface of the sail; required, the propelling and leeway components of the wind, supposing its force to be represented by 10.

Wind's angle with sail	22½°	L. sine	9·5828
Sail's angle with keel	34°	L. sine	9·7476
Wind force	10	log	1·0000
Effective propelling force	2·14	log	0·3304

Wind's angle with sail	22½	L. sine	9·5828
Sail's angle with keel	34°	L. cos.	9·9186
Wind force	10	log	1·0000
Leeway force	3·17	log	0.5014

In this example the ship is sailing within 5 points of the wind, which gives the effective propelling force less than the force which is driving her to leeward.

Example II.—The yards are braced up to an angle of 4 points with the keel, and the wind makes an angle of 2 points with the sail; required, the propelling and leeway forces, when the wind force is 10.

Wind's angle with sails	22½°	L. sine	9·5828
Sail's angle with keel	45°	L. sine	9.8495
Wind force	10	log	1·0000
Effective propelling force	2·76	log	0·4323

Wind's angle with sail	22½°	L. sine	9·5828
Sail's angle with keel	45	L. cos.	9·8495
Wind force	10	log	1·0000
Leeway force	2·76	log	0·4323

In this example the propelling and leeway components are equal, and the propelling component is greater than it was when the ship was lying a point higher; from this we learn that the apparent gain in the direction of the ship's head is lost in leeway, and reduced speed results when the yards are braced sharper than four points, *i.e.*, when the angle between the ship's head and the supposed flat surface of the sail is less than four points.

Example III.—The sails make an angle of 4½ points with the keel, and the wind with force 10 makes an angle of 2 points with the sail; required, the propelling and leeway forces.

Wind's angle with sail . .	22½°	L. sine .	9·5828
Sail's angle with keel . .	50½°	L. cos. .	9·8035
Wind force	10	log .	1·0000
Leeway force	2·43	log .	0·3863

Wind's angle with sail . .	22½°	L. sine .	9·5828
Sail's angle with keel . .	50½°	L. sine .	9·8874
Wind force	10	log .	1·0000
Propelling force . . .	2·95	log .	0·4702

Showing that while the force of the wind and the angle it makes with the sail remain the same, the propelling force increases and the leeway force diminishes as the yards are checked in.

These examples may be solved by means of the traverse table. Enter the table with the angle the wind makes with the sail as a course and the wind force as a distance, for which take out the departure, which will be the propelling force of the wind, and the difference of latitude against these will be the leeway force.

Taking the last example, and calling the angles 23° and 51°, under course 23°, distance 10, we get 3·9 dep.; under course 51°, distance 3·9 we get:

Departure 3·0 = propelling force,
And diff. lat. 2·45 = leeway force.

It must be understood that the wind force of 10 used in these examples does not mean the wind force of 10 in the Beaufort scale, but is merely adopted for convenience of calculation, and may be considered to represent either pressure or velocity; since all that is required to be known in this general treatment of the problem is the ratio of the propelling force to the total wind force. In the case of the jibs it will be seen upon investigation that one of the components of the wind force on these sails acts upwards and helps to lift the ship's head, thereby reducing her pitching in a head sea. On resolving the wind force on the foresail when running, an upward component is also derived. The foresail is therefore a lifting sail when the ship is running.

We will now give an example of a ship with the wind four points on the quarter.

Example IV.—The yards of a ship are braced forward 2 points, the wind is 4 points on the quarter; required, the propelling component of the wind's force considered as 10.

Here the sails make an angle of 6 points with the keel, and the wind makes an angle of 6 points with the surface of the sail;

therefore these two angles are equal; and, since our rule gives the propelling force of sails, propelling force = 10 × sin. ϕ sin. θ = 10 × sin.^{2} ϕ,

Therefore,	ϕ 67½°	L. sin.	9·9656
			2
		L. sin.^{2}	9·6312
Wind force	10	log	1·0000
Propelling force . . .	8·54	log	0·9312

Suppose now the wind to be 2 points in the quarter, while the sails still make an angle of 6 points with the keel, then the wind blows perpendicularly into the sails.

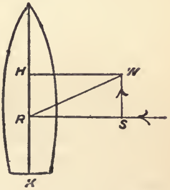
Wind's angle with sail .	90°	L. sin.	10·0000
Sail's angle with keel .	67½°	L. sin.	9·9656
Wind force . .	10	log	1·0000
Propelling force . .	9·24	log	0·9656

Which is very nearly equal to whole wind force.

When the wind blows perpendicular to the surface of the sail the ship steers badly; the yards are therefore trimmed so that the wind may strike the surface of the sails obliquely.

Deflection of the Wind.—We have as yet said nothing about the drawing forward of the wind owing to the ship's motion, and the examples we have worked out have only dealt with the apparent direction of the wind; we will therefore now consider the difference between the true and apparent direction of the wind, caused by the ship's motion.

FIG. 37.



Let HK (Fig. 37) be the ship's keel, W is a particle of air moving in the direction WH, with the velocity WH, while the ship is moving in the direction KH, with the velocity RH; therefore, by the time that the particle W arrives at the line of the keel, the ship will have moved through the distance RH, and the particle W will strike the line of keel at R, and if it were visible, would appear to come from the direction RW, the resultant of the velocities of the ship and the wind; complete the parallelogram HRSW, and we get the angle HWR equal to the angle SRW, which is the angle through which the wind is deflected or drawn forward of its true direction. Since RH and HW are known we get

$$\text{tan. HWR} = \frac{\text{RH}}{\text{HW}} = \text{tan. deflection SRW.}$$

EXAMPLE I.—Suppose a vessel's speed to be 10 miles an hour and the wind's velocity 20 miles an hour, the true direction of the wind being abeam, what will be its apparent direction?

$$\text{tan. deflection} = \frac{10}{20} = 0{\cdot}5$$

or by logs,

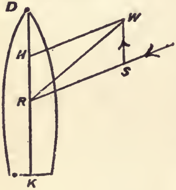
Speed ship . = 10′ log 1·0000
Velocity of wind = 20 log 1·3010

Deflection = 26°34′ tan. 9·6990

That is, the apparent direction of the wind would be 27° before the beam.

The same result may be obtained from the traverse table, which enter with 20 as a diff. lat. and 10 as a dep.; the course will be the deflection of the wind; the nearest is diff. lat. 19·6 dep. 10, which gives 27°. When a ship is sailing within 6 points of the wind the triangle formed by the velocity of the wind, the speed of the ship and their resultant is no longer a right-angled triangle, and therefore cannot be solved by the rule just given, but may readily be solved by construction.

FIG. 38.



Let HK (Fig. 38) represent the keel; draw HW making the angle DHW equal to 6 points; lay off HW equal to the wind's velocity, and HR equal to the speed of the ship; complete the parallelogram RHWS and the diagonal RW will represent the apparent direction of the wind; the angle WRS is its deflection.

In the triangle RSW we have given the two sides RS and SW together with the included angle RSW to find the angle WRS.

RULE.*—*As the sum of the two sides is to their difference, so is the tangent of half the sum of the two unknown angles to the tangent of half their differences.*

$$\text{RS} + \text{SW} : \text{RS} - \text{SW} :: \text{tan.}\ \tfrac{1}{2}(\text{WRS} + \text{SWR}) : \text{tan.}\ \tfrac{1}{2}(\text{WRS} - \text{SWR}).$$

A vessel is sailing within 6 points of the wind, her speed is

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[*] For this rule the reader is referred to Buck's *Practical Algebra and Trigonometry*, in Griffin's "Nautical Series."

7 knots, and the velocity of the wind is 20 knots, how much will the wind draw forward of its true direction?

Here we have the angle RSW = the angle RHW, and therefore = 10 points; the sum of the two angles WRS, SWR, is therefore = 6 points; and SW = 7, RS = 20 are the given sides; therefore—

$$27 : 13 :: \tan.\ \frac{67\frac{1}{2}^\circ}{2} : \tan.\ \frac{(\text{SWR} - \text{RWS})}{2}$$

13 log 1·1139
$\frac{1}{2}$ sum $\frac{67\frac{1}{2}^\circ}{2}$ tan. 9·8249
27 ar. co. 8·5686

$\frac{1}{2}$ diff. 17°50 tan. 9·5074
$\frac{1}{2}$ sum 33°45′
WRS = 15°55′ = the deflection of the wind from its true direction.

Half the difference of the two angles subtracted from half their sum gives the lesser angle, and in our case WRS is the lesser angle.

The apparent direction of the wind is therefore $3\frac{1}{2}$ points before the beam.

Apparent and True Velocity of the Wind.—The force and velocity of the wind are apparently increased by this drawing forward. In the case just considered of a ship sailing 6 points from the wind the side RW of the triangle RSW will represent the increased force of the wind due to this cause, and as the sides of a triangle are to each other as the sines of their opposite angles, we have the angle SWR = 51° 35′ and the angle WRS = 15° 55′; also the angle WSR = 112° 30′; we may therefore either use 15° 55′ and its opposite side, or 51° 35′ and its opposite side, which is the true force or velocity of the wind; and since it is the wind's apparent force we want we will use the latter; therefore:

Sin. 51° 35′ : sin. 112°30′ : : 20° : app. force
App. force = cosec. 51°35′ sin. 112°30′ × 20

112°30′ L. sin. 9·9656
51·35 L. cosec. 10·1059
True wind velocity . . 20′ log 1·3010

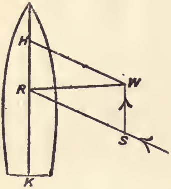
App. wind velocity . . 23·6 log 1·3725

When the true direction of the wind is abeam, the apparent increase in its velocity will be equal to its true velocity multiplied by the secant of its angle of deflection. Let us take example I., where we get the deflection = 26° 34′, and wind velocity 20.

Wind's deflection . .	26°34′ ∠.	sec.	10·0484
Wind's true vel. . . .	20	log	1·3010
Wind's app. vel.. . .	23·4	log	1·3494

Apparent Direction and Velocity of the Wind.—We will now consider the case of the wind abaft the beam. In Fig. 39, HR is the ship's fore and aft line, SR is the velocity and direction of the wind, RH or SW the speed and direction of the ship's motion; then WR is the apparent direction and velocity of the wind.

FIG. 39.



Suppose the true direction of the wind is abaft the beam one point or $11\frac{1}{4}°$ with velocity 20 knots, and the ship's speed 11 knots, then we have the two sides WS = 11 and SR = 20, together with the included angle WSR, to find the angle of deflection SRW; therefore WSR = 7 points = 78° 45′; therefore, the sum of the angles R and W is 9 points = 101° 15′.

Therefore 31 : 9 : : tan 50° 37′ : tan $\frac{1}{2}$ diff. angles R and W.

$$\frac{9 \times \tan.\ 50^\circ\ 37'}{31} = \tan.\ \tfrac{1}{2}\,(W - R)$$

Sum of sides	31	ar. co.	8·5087
Diff. sides	9	log	0·9542
$\frac{1}{2}$ sum of angles	50° 37′	tan.	10·0857
$\frac{1}{2}$ diff. ,, ,,	19 29	tan.	9·5486
Angle R	31° 8′	=	Wind's deflection forward of the true direction.
,, W	70 6		

Therefore, the apparent direction of the wind is equal to

31° 8′ − 11° = 20° before the beam.

We will now find the apparent velocity of the wind to this deflection, for which we have the rule:

$$\text{sin. W} : \text{sin. S} :: \text{RS} : \text{RW}$$

$$\therefore \quad \text{RW} = \text{sin. S} \times \text{RS} \times \text{cosec. W}$$

$$= \sin 78^\circ\ 45' \times 20 \times \text{cosec. } 70^\circ\ 6'$$

Angle	W =	70° 6′	cosec.	10·0267
„	S =	78 45	sin.	9·9916
Wind's true vel.		20	log	1·3010
„ app. vel.		20·9	log	1·3193

Taking another case with the wind's true direction 2 points abaft the beam, which gives us the angle S equal to 6 points; therefore the sum of the angles R and W is 10 points = 112° 30′, and considering the velocity of the wind and speed of the ship the same as in the last example we get

$$31 : 9 :: \tan 56^\circ\ 15' : \tan (\text{W}-\text{R}).$$

Therefore

$$\tan \tfrac{1}{2}(\text{W}-\text{R}) = \frac{9 \times \tan 56^\circ\ 15'}{31}$$

Sum of sides	=	31	ar. co.	8·5087
Diff. of „	=	9	log	0·9542
$\frac{1}{2}$ (W + R)	=	56° 15′	tan.	10·1751
$\frac{1}{2}$ (W − R)	=	23 29	tan.	9·6380
Angle R	=	32 46	= deflection of the wind.	
„ W	=	72° 44′		

The apparent direction of the wind is therefore

$$32^\circ\ 46 - 22^\circ\ 30 = 10^\circ\ 16''$$

before the beam, or nearly one point.

For the apparent velocity we have

$$\text{sin. } 79^\circ\ 44' : \text{sin. } 67^\circ\ 30' :: 20 : \text{WR}$$

Therefore

$$\text{WR} = \text{cosec. } 79^\circ\ 44' \text{ sin. } 67^\circ\ 38' \times 20$$

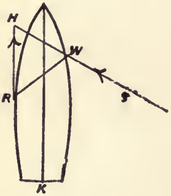
Angle	W =	79° 44′	cosec.	10·0070
„ S	=	67 30	sin.	9·9656
Wind's true vel.		20	log	1·3010
Wind's app. vel.		18·8	log	1·2736

In this case the apparent velocity or force of the wind is less than the true one, notwithstanding that the wind is drawn forward of the beam.

The inverse of these problems may be calculated if the apparent direction and velocity of the wind are given together with the relative course and speed of the ship. But the readiest solution of all these problems is by the method of construction, which can always be easily effected on board ship by means of a protractor, a rule, and the longitude scale of any chart.

Illustration of a Shot Fired through a Ship.—A familiar illustration may assist in conveying a clearer conception of the wind drawing forward when it is blowing from a point abaft the beam. Suppose in Figure 40 a shot S fired into a ship from a point 4 *points* abaft the beam and to enter the ship at W; then, if she were stationary it would pass out on the port side at the point H; but we will suppose the speed of the ship to be equal to the speed of the shot, therefore, while the shot is moving through the ship in the direction WH the ship is moving in the direction RH with equal speed, and by the time that the shot has reached the port side the point R has moved into the position of the point H; therefore the shot S will pass out of the ship at R, a point situated abaft the point at which it entered, and WR will be its apparent path. In the triangle WHR the side WH is equal to the side RH; therefore the angle R is equal to the angle W, and the angle H is equal to 4 points, therefore the angle equal to 6 points is the angle which the apparent path of the shot makes with the ship's head. If we enter the traverse table with the speed of the ship as a distance and 6 points as a course the difference of latitude will be equal to half the apparent velocity of the shot.

FIG. 40.

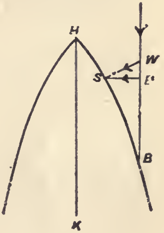


Suppose, again, that WR is a tube then the shot entering it at W would pass through it in the direction WR without striking against its side so long as the tube continued its motion in the direction RH with a velocity equal to that of the shot.

Pressure of the Water on a Ship's Bows.—When a ship is sailing upright, which only happens when the yards are square, the pressure of the water on the bows is equally balanced, unless she is rolling, when the alternating difference in the immersion of the bows is one of the contributing forces to her unstable motion. Under any other direction of the wind the ship maintains a more or less permanent heel to leeward, whereby the weather bow is raised out of the water and the lee bow more deeply immersed. It is this difference between the immersion of the bows which causes the ship to "gripe." We will therefore investigate the principles of the problem, which come under the inclined plane.

Suppose the speed of the ship transferred to the water, while the ship is supposed to be at rest.

FIG. 41.



Let HK (Fig. 41) be the ship's keel, HB the bow, WB the direction and velocity of the water on the bow. Draw WS perpendicular to the surface of the bow; then the force WB is resolved into two forces acting at right angles to each other; WS is the effective pressure of the water on the bow, and the component SB merely glides along the surface of the bow and produces no effect. Again, resolve WS into its components, WP parallel to the keel, and PS at right angles to the keel; we have therefore WP, which reduces the ship's speed, and PS, which drives the ship's head to windward, by its action on the excess of the immersed surface of the lee bow over that of the weather bow. Since a ship's bow has always a flange which increases its over-hang of the water by the heeling of the vessel, the effect of the water pressure will have an upward direction in addition to the two horizontal directions; but as the inquiry is only into the general nature of the problem, we will only consider the horizontal components of the water pressure, and find a rule for computing them.

WSB is the mean angle which the stream makes with the bow, and SB must be considered as a straight line tangent to the bow at the point S. WSB is a right angle; therefore, the angles SBW and SWB are together equal to a right angle; but so also are the angles SWB and PSW together equal to a right angle; from each of these right angles take SWB and we get SBW equal to WSP.

$$\text{WS} = \text{WB sin. SBW}$$

$$\text{SP} = \text{WS cosin. WSP}$$

But SBW = WSP. Call this angle ϕ, and since

$$\text{WS} = \text{WB sin. } \phi$$

we get

$$\text{SP} = \text{WB sin. } \phi \text{ cosin. } \phi$$

$$= \frac{\text{WB}}{2} \text{sin. } 2\,\phi$$

This is the griping force of the water pressure on the lee bow, and may be stated as follows:—

The force of the water in driving the ship's head into the wind is equal to the sine of twice the angle the direction of the stream makes with the surface of the lee bow multiplied by half the ship's velocity.

The component WP is the component which resists the ship's motion.

$$\mathrm{WP} = \mathrm{WS} \sin. \phi$$

Substituting the value of WS already found, we get

$$\mathrm{WP} = \mathrm{WB} \sin.^2 \phi$$

Therefore the pressure on both bows is

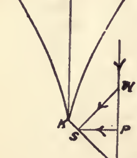
$$2\mathrm{WP} = 2\mathrm{WB} \sin.^2 \phi$$

and may be stated verbally thus:

The pressure on the ship's bows resisting her motion is equal to twice the velocity or pressure on the bow multiplied by the sine square of the angle the surface of the bows makes with the stream.

Forces on the Rudder when Upright.—The ship's tendency to gripe has to be counteracted by the helm; we will therefore consider how the water acts upon the rudder.

FIG 42.

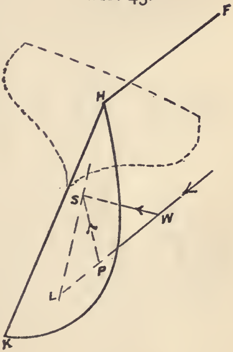


Let HK (Fig. 42) be the ship's keel, KR the rudder, WR the magnitude and direction of the stream acting upon it. Draw WS perpendicular to the surface KR of the rudder; then WS is the effective water force acting upon it. From S draw SP perpendicular to WR; then PS is the turning force of the helm, and WP is its dragging force, since it acts in opposition to the ship's motion.

Forces on the Rudder when Heeling.—As was stated in the article on the water pressure on the lee bow, the action of the water should strictly be resolved in three directions when the vessel heels. We will therefore consider, separately, the upward, or lifting force, of the water on the rudder; for its surface area being small, it has its turning power very much reduced by the heel of the ship. The tendency of the ship to gripe increases with the heel, while the turning power of the rudder decreases with it, and vanishes altogether when the vessel is on her beam ends.

Let HK (Fig. 43) be the sternpost heeled over, HF a fore-and-aft mid-ship line parallel to the keel and in the same vertical plane. Since in the figure we only see the back of the rudder, we will suppose it to be transparent, and that we can see the water impinging on its forward side in the direction WL, represented by dotted lines; draw WS perpendicular to the surface of the rudder; then WS is the total effective force of the water on its surface. From S draw SP perpendicular to WL, which lies in a plane parallel to the surface of the water; SP is, therefore, the upward, or lifting force, acting on the rudder when the vessel heels. The turning force is not shown in the figure, since LP is in a vertical plane, and must be resolved in a horizontal plane for the turning force.

FIG. 43.

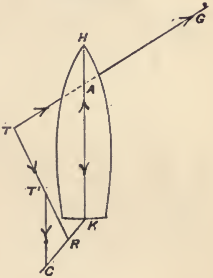


It will be understood from the foregoing why, when a vessel is heeled over by a squall she will not pay off, and must, therefore, be assisted off the wind by easing off the main and spanker sheets, and sometimes shivering the cross-jack yard, and even then she may refuse to pay off as long as the violence of the wind continues.

This, therefore, shows the necessity of getting a ship off the wind before a squall actually strikes her, that is, when the wind is just abaft the beam.

Sheering a Ship at Anchor and Dredging.—A ship at her anchor is held in equilibrium by her anchor and the current acting upon her rudder and hull in opposition to each other.

FIG. 44.



Let HK (Fig. 44) represent the keel, RC the rudder, AG the cable and anchor, which produce to AT; T'C is the current in magnitude and direction, and TR is its effective force on the rudder perpendicular to its surface RC. In the triangle ATR,* we have AT equal to the strain on the cable, TR equal to the current's effective action on the rudder, and AR as a resultant. The ship is therefore maintained with her keel parallel to the direction of the current by the triangle of forces, which is a system of equilibrium. The tendency of

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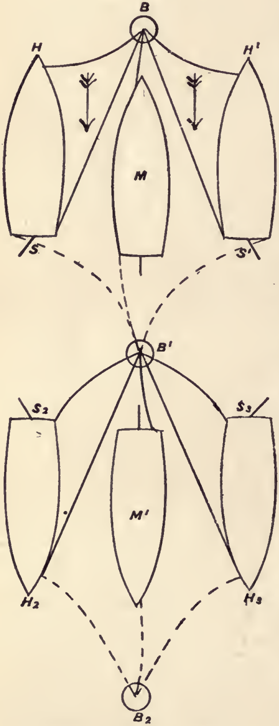
R must be supposed to coincide with K when the triangle ATR is dealt with—*i.e.*, imagine the line TR to move parallel to itself until R reaches K.

the ship when the helm is put a-starboard is to sheer herself into the direction TR, when the action of the current on her starboard bow carries her away from her anchor G, and at the same time straightens her into line with itself by acting upon that part of her keel and hull which is abaft the hawse-pipes.

FIG. 45.



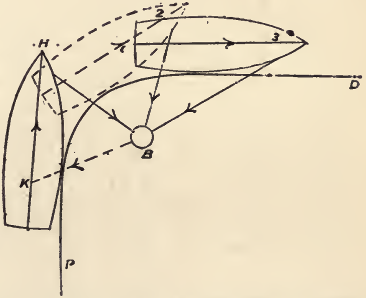
In the absence of wind the amount of sheer will be regulated by the strength of the current, and the amount of helm applied. If the cable be hove short, so as to break out the anchor, the ship will start away with it in the direction AT across and down stream ; this is called *dredging* and is a very safe and convenient method of getting across a river from one bank to the other, or from the middle of a stream to a pier or dockhead and *vice versâ*.

Getting a Vessel out of a Tier.—When three or more vessels are lying in a tier moored head and stern to two buoys, one of which is ahead and the other astern, the vessels hang pretty heavily together by the force of the stream, but this pressure may be considerably relieved by a spring taken from the quarter of each of the outside vessels to the buoy to which they are riding, also another spring from the bow of each outside vessel to the buoy astern ; they are thus in a position to open out or separate from each other, whether they are riding by the head or the stern, whereby a vessel in the middle of the tier may be enabled to get readily out of the tier.

In Fig. 45 we will employ three vessels to illustrate the operation, which will be the same whether there are three or seven in the tier.

Let B be the buoy to which three vessels are hanging by the head, BS and BS′ are springs to their quarters, BH and BH′ are their head mooring chains. The helm of the vessel HS is put to starboard and the head and stern chains are slacked up, when the action of the stream sheers her off to the position HS, the spring BS preventing her from coming astern, so that she may return to her former distance astern of the buoy. The helm of the vessel H′S′ is put to port while the head and stern chains are slacked up and she sheers into the position H′S′; the middle vessel M is now free to get out of the tier stern first. But it is just as likely that one of the inside vessels may want to get out of the tier when they are hanging by the stern to the buoy B′. In the figure the arrow shows the direction of the stream; B′ is the buoy to which the vessels are hanging. The vessel S_2H_2 has a spring H_2B' to the buoy and the vessel S_3H_3 has also a spring H_3B' to the buoy; both these springs are taken from the inside bows and hauled taut. The helm of S_2H_2 is ported while S_3H_3 starboards her helm; the stern and head mooring chains are then slacked up and the outside vessels sheer off to the positions S_2H_2, S_3H_3 leaving, as in the former case, the middle vessel M′ free to get out of the tier, but in this instance head first. The mooring chains to which the outside vessels are hanging must only be slackened sufficiently to allow them to sheer into the necessary position while the chains over which the departing vessel passes must be paid out sufficiently to clear that vessel's keel.

FIG. 46.

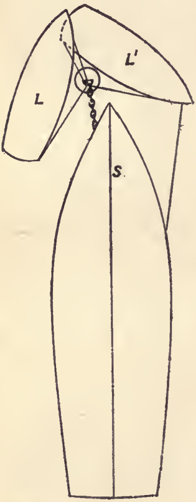


Turning a Pier-Head.—A steamer may be turned round a pier-head by means of a spring from the bow and the engines going slowly ahead, as for example entering a dock.

Let PBD (Fig. 46) be a pier-head, D being in the dock entrance, and P in the stream outside. A vessel gets into the position HK with a spring HB to the bollard B; the engines propel her in the direction KH, shown by the arrow, the spring HB pulls her bow towards B and the pier-head thrusts her off in the direction BK; we have therefore three forces acting round a triangle in the same direction, viz., from K to H, from H to B and from B to K; the system is therefore one of unstable equilibrium, and motion round the immovable point B is the result. If the drift of the spring HB is not altered, the vessel will steadily move into the position of the dotted figure (2) and finally into that of the plain figure (3).

In practice the width of the dock entrance does not usually permit a large vessel to turn round the pier-head with the original drift of spring; it is therefore steadily hove in either by the ship or by a capstan on shore, and fleeted along the quay from time to time until the vessel is straightened into the dock entrance.

Fig. 47.



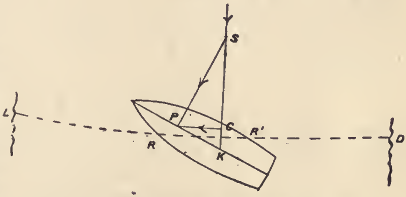
In entering a dock from a river wherein the tide runs strongly it is necessary to get the vessel at least more than half her length across the entrance, before springing her in, otherwise the stream will retain full command of her and throw an enormous strain on the spring, which will be a force applied obliquely at the short arm of a lever to overcome the greater force of the current or stream acting on the longer arm, round the pier head as a fulcrum. Besides there is a great loss of time in getting the vessel into position.

Shifting Lighters from one Side of the Ship to the other.—By a similar process to the foregoing a barge or lighter may readily be shifted from one side of a vessel to the other without the necessity of towing or sweeping her round, that is, if she must be taken round the bows of the ship owing to other lighters being alongside fore and aft the ship. By means of a line to the knight-heads haul the lighter under the bow and get a line bent to the ship's cable, then let go the line from the knight-heads and make it fast to the cable also; walk aft on the lighter with it and shoot her ahead, while the head line is being slacked away, as shown at L in Fig. 47, and continue hauling on the after line until she cants round the cable or buoy as shown at L′; if this operation is carried out in a current the lighter will now only require to be slacked down to her position alongside the ship, but in the absence of a current a hauling line may be passed aft on the ship and the lighter hauled into position.

Propelling a Boat by the Stream.—Propelling a boat across a stream by the action of the stream upon her keel and side is a useful practical application of the resolution of forces well known to ferrymen in many places.

A small chain is laid across the bed of the stream. The boat under-runs this chain which passes over a rowlock on one bow and over another on the opposite quarter, this holds the boat with her head pointing obliquely up the stream; the boat thus becomes a movable inclined plane; the current striking obliquely on her keel and side causes her to move in the direction of least resistance, which is to slide along the chain and thereby shoot across the stream.

Fig. 48.



Let LD (Fig. 48) be the chain which the boat under-runs, RR′ the rowlocks over which the chain passes, SK the direction and magnitude of the stream striking the boat's keel at K. Draw SP perpendicular to the keel, then SP is the total effective component of the stream's force acting upon the boat; the component PK merely glides along the keel and produces no effect on that portion of the boat, but it has a retarding effect upon the entrance of the bow; however, that is compensated by the propelling effect it has upon the run of the boat's quarter.

The effective component SP must be again resolved into the force PC, which propels the boat across the stream, and the force SC, which drives the boat down the stream, but is counteracted by the chain LD. SKP is the angle which the stream makes with the keel; and since the triangle SPK is a right-angled triangle, the angles PKS and KSP are together equal to a right angle, but the triangle PSC is also a right-angled triangle; therefore, the angles SPC and CSP are together equal to a right angle, and since CSP is the same angle as KSP, we get, by taking this common angle from each of the right angles, SKP equal to CPS. We are now in a position to calculate what portion of the stream's force is effective in shooting the boat across the stream.

In the triangle SKP we get—

$$SP = SK \text{ sin. } SKP \qquad (1)$$

In the triangle SPC we get—

$$PC = SP \text{ cosin. } SPC.$$

But the angle SPC has been shown to be equal to the angle SKP—

Therefore, $PC = SP \text{ cosin. } SKP$;

substitute the value of SP found in equation (1) and we get—

$$PC = SK \text{ sin. } SKP \text{ cosin. } SKP.$$

Let $SKP = \phi$, then—

$$PC = SK \text{ sin. } \phi \text{ cosin. } \phi$$

But $\text{sin. } \phi \text{ cosin. } \phi = \frac{1}{2} \text{ sin. } 2\phi$.

Therefore,

$$PC = \frac{SK}{2} \text{ sin. } 2\phi \qquad (2)$$

Which may be stated thus: *The force which shoots the boat across the stream is equal to half the force of the stream multiplied by the sine of twice the angle which the stream makes with the boat's keel.*

SC is the force driving the boat down stream; therefore we get—

$$SC = SP \text{ sin. } \phi$$

Substitute the value of SP in equation (1)

$$SC = 2K \text{ sin.}^2 \phi \qquad (3)$$

That is: *The force which shoots the boat down stream is equal to the force of the stream multiplied by the sine square of the angle the stream makes with the boat's keel.*

Suppose, for example, the force of the stream to be 10 and the angle at which it strikes the boat's keel to be 60°, what will be the force shooting the boat across the stream?

Equation (2) $PC = \frac{10}{2} \text{ sin. } 120° = 5 \text{ cosin. } 30°$

Half force of stream . . = 5 log. 0·6989
Complement of twice the angle = 30° cosin. 9·9375

Propelling force . . . . = 4·3 log. 0·6364

That is, less than half the force of the stream is effective in propelling the boat when the angle it makes with the keel is 60°; of course, this gives us no idea of the absolute force of the stream or the speed of the boat, but it gives the relative value of the force made use of.

For the force driving down stream we have equation (3)—

$$SC = SK \sin.^2 \phi$$

Force of stream . . . = 10, log. 1·0000
Angle with keel . . . = 60° $\sin.^2$ 9·9751

Force driving with stream . 9·4 log. 0·9751

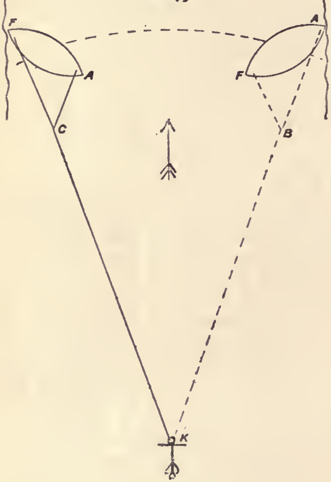
which is very nearly equal to the whole force of the stream.

It has been assumed that the chain under-run by the boat is straight, like an iron rod; but this is impossible in practice, because the chain must lie slack on the bed of the stream to enable it to be under-run; therefore the boat drifts down stream on the bight of it as shown in the figure, and has therefore on nearing the opposite bank to shoot up stream. Although it may never be necessary to make calculations respecting this taking advantage of the force of a stream, yet it is useful to know how the thing works, or to quote an expression of Clerk Maxwell's "to know the go of the thing," and learn that it is in accordance with well-known physical laws; such knowledge will always be worth storing up, especially by the sailor, who is so much thrown upon his own resources in making the most he can out of the natural forces; when the more exact his knowledge is of natural laws the more readily will he be able to avail himself of the forces at hand.

Another application of propelling a boat across stream by the resolution of the force of the stream may be seen on the Rhine.

A long wire rope is anchored at K in the bed of the river (Fig. 49), at C this rope is fitted with a bridle and the legs CF and CA, taken one to each end of the boat FA, where winches are fitted for the purpose of heaving in or veering away on the legs of the bridle. Now, suppose the ferry-boat at P and hanging to ACK, the rope FC is shortened in by the winch until the boat is in the position FA, when the stream shoots her across to S, describing an arc of a circle PS round the anchor at K. To return from S, where we suppose the boat to be hanging by FBK, the rope AB is rounded in by the winch until she is in the position FA in the dotted figure, when the stream shoots her back to the point P. If both legs of the rope are adjusted to the same length the boat will lie square athwart in mid-stream and will not move towards either bank of the river.

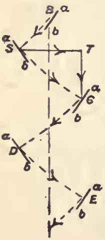
FIG. 49.



It will be obvious that the motion of the boat from the bank to the middle of the stream will be more rapid than from the middle of the stream to the bank, for the reason that in the former case she is going partially with the stream, but in the latter she is going partially against the stream.

Sculling.—Sculling as practised by the sailor is propelling a boat by an oar shipped in a crutch in the stern or over the quarter. The mechanical principle of this sculling is a combination of the lever and the movable inclined plane. The point of resistance is the crutch in the boat's stern, the power is the hand on the oar, and the fulcrum, which is a movable one, is the feather of the oar (which performs the part of a movable inclined plane), and the water. The feather of the oar is turned obliquely to the direction of the thrust, which, by a dexterous and skilful turn of the wrist, is oscillated from side to side with the result that the boat is propelled ahead.

FIG. 50.

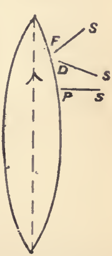


In Fig. 50, let B be the position of the oar in the water at the beginning of the stroke, *ab* represents the inclination of the feather of the oar. The first stroke, which is only half a one, brings the feather to S, the next stroke brings the feather to C, and so on, making a zigzag track as shown in the figure. At S, *ab* shows the inclination of the feather, and the thrust is made in the direction ST, but because the feather is a movable inclined plane the real track of the oar is SC, which is the resultant. Resolving this, draw ST equal to the length of the thrust, and at right angles to it draw TC; then TC is the distance the boat is propelled ahead at each thrust of the oar. The real track of the oar is not a zigzag of straight lines, but of somewhat curved lines, convex to the boat's stern, as shown in the figure.

Rowing.—Rowing is the most familiar method of propelling a boat and is much simpler than sculling. It is effected by the oars being used as levers of the second kind or order, where the resistance is the rowlock in the boat's gunwale, the power is the hand and the fulcrum is the water.

Paddling a Canoe.—Paddling is the most primitive method of propelling a canoe or boat and requires a greater expenditure of physical force to produce an equivalent result to that obtained by rowing with oars. The Pacific Islanders and other primitive races use the paddle, but with considerable skill, and one man may be seen paddling his canoe as straight as an oared galley, by using the paddle on one side only, usually at the stern. It is therefore not necessary to use the paddle on each side of the canoe alternately, for the purpose of steering her; as we will show by Fig. 51.

FIG. 51.



Let FDP represent the bow of a canoe, which is being propelled by a paddle, whose blade is represented by PS, the thrust will be perpendicular to PS, and therefore parallel to the line of motion, which will cause the canoe to shoot ahead, but her direction of motion will be very much like that of a ship running with the wind right aft as was explained in the article on the ship considered as a lever. Therefore to steer, as well as propel, the canoe with only one paddle, it must be feathered according to the direction in which it is desired to turn her head. Suppose we wish the canoe to turn her head to *port*, the paddle must be feathered in the direction FS; the effective force of the thrust is perpendicular to FS, and therefore oblique to the line of motion; it therefore, for reasons shown in a previous article, propels the canoe at the same time that it turns her head to port. Suppose next that we wish to turn her head to starboard, the paddle must be feathered in the direction DS; the force applied to DS will be a pull, effectively perpendicular to DS, and oblique to the line of motion; the head of the canoe will therefore turn to starboard, at the same time that it is propelled ahead by the pull.

The skill necessary to steer and propel a canoe by one paddle, used on one side of the canoe only, can only be acquired by much practice; so dexterously do some of the Pacific Islanders paddle their canoes that the feathering of the paddle is not perceptible to an uninitiated observer.

In the case of paddling from the stern of the canoe, the feathering of the paddle would be the reverse of what has been given for paddling from the bow. To turn her head to port a pull would be given to the paddle, and to turn her head to starboard a thrust would be given.

Unlike sculling a boat, which is always done standing erect in the stern sheets, paddling must be performed seated, otherwise the canoeist may find himself in the water, having gone after his paddle while giving a too vigorous pull for his craft to readily answer; and it requires some considerable art to re-enter a small canoe without capsizing her, especially if there is no second occupant.

CHAPTER XII.

HYDROSTATICS.

Hydrostatics is that branch of statics which treats of the equilibrium of fluids, whether liquid or gaseous.

Fluids yield without resistance to the smallest force impressed upon them; they are divided into two classes, *elastic* and *non-elastic* fluids. An *elastic* fluid is one, the dimensions of which may be diminished by increasing the pressure upon it, and increased by diminishing the pressure. Vapours, gases, and common air are elastic fluids.

A *non-elastic* fluid is one which suffers little or no diminution in its dimensions by any pressure, however great, such as mercury, spirits, water and other liquids.

The only fluids we shall deal with in this article are *common* air and *water*. The rules are drawn up for gases, but are common to all elastic fluids. The rules applied to water are also common to all non-elastic fluids.

We will give here some data which will be useful throughout this article.

Fresh water.	Specific gravity = 1. 1 cubic foot weighs 62½ lbs. = 1000 oz. 1 gallon weighs 10 lbs. 1 ton fills 35·85 cubic feet. 1 atmosphere = 14·73 lbs. per square inch with barometer at 29·92 inches. = 34 feet head of water. 1 foot head of water = ·43 lb. on square inch.
Sea water of the density of the Irish Sea.	Specific gravity = 1·028. 1 cubic foot weighs 64 lbs. 1 gallon weighs 10¼ lbs. 1 ton fills 35 cubic feet. 1 atmosphere = 32·9 feet, with barometer at 29·92 inches. 1 foot of head = ·44 lb. per square inch. 1 cubic inch = ·037 lb.

Atmospheric Pressure.—The earth is surrounded by a shell of air called the atmosphere, which, although apparently without weight, so far as the senses can tell, exerts a pressure at the earth's surface of about 15 lbs. on the square inch; this is ascertained from the fact that it supports a column of mercury of about 30 inches in height, or a column of water 34 feet in height. As we ascend above the sea level, not only does the pressure become less, but the air is more attenuated or thinner the higher we ascend, and at great altitudes produces unpleasant sensations. On the other hand, when we are subjected to an increase of atmospheric pressure, such as may be experienced in a diving-bell, where the pressure may be equal to that of several atmospheres, similar sensations are felt.

The Mercurial Barometer.—This instrument consists of a glass tube about 32 inches in length filled with mercury and inverted with the open end in a trough or cistern of the same metal. The column of mercury retained in the tube represents the weight of a column of the earth's atmosphere having the same sectional area as the column of mercury. Suppose the column of mercury to be a square inch in section and 30 inches in height, we get for its weight, since a cubic inch of mercury weighs 0·497 lb—

$$\cdot 497 \times 30 = 14{\cdot}9 \text{ lbs.}$$

which represents the pressure of the atmosphere.

The specific gravity of mercury is 13·57, and that of water is 1; therefore the height of a column of water equal in weight to the atmospheric pressure when the barometer stands at 30 inches is:

$$1 : 13{\cdot}6 :: 30 : \text{height of water column.}$$

Therefore,

$$\text{height of water column} = 13{\cdot}6 \times 30 = 408 \text{ inches} = 34 \text{ feet.}$$

Owing to the diminishing pressure of the atmosphere as we ascend above the earth's surface the barometer affords a ready means of finding the height above the sea level or the elevation of one station above another, when the height of the barometer is known at both stations simultaneously.

The barometer falls 1 inch for an elevation of from 918 to 930 feet for moderate altitudes above the sea level; knowing this we are able to find the difference of elevation of two places from the difference in the height of the barometer by the proportion.

$$1 \text{ inch} : \text{diff. barometers} :: 918 \text{ feet} : \text{diff. elevation.}$$

Suppose the barometric difference at two stations to be 0·70 inch, find the difference of elevation,

$$1 : 918 :: \cdot 70 : \text{diff. elevation.}$$

Therefore,

$$\text{Difference of elevation} = 918 \times \cdot 7 = 642{\cdot}6 \text{ feet.}$$

The **Aneroid barometer,** being more sensitive and portable than the mercurial barometer, is most usually employed for the purpose of measuring differences of elevation.

Suppose an aneroid barometer carried up to the *top-mast cross-trees* was observed to fall 0·12 of an inch after leaving the deck, what is their height above the deck?

1 : 918 : : 0·12 : height of cross-trees.

Therefore,

Height of cross-trees = 918 × 0·12 = 110·2 feet.

Boyle and Mariotte's Law. Effect of Pressure on Gases.—When a gas is compressed its elastic force is increased; and *vice versâ;* when it is allowed to expand its elastic force becomes less. This law is named after its discoverers the Hon. Robert Boyle in England and Mariotte in France. The law may be thus stated:

The elastic force of a given mass of gas, the temperature remaining constant, varies inversely as the volume it occupies.

In the practice of the sailor atmospheric air is about the only gas which may usefully be considered, since it is this law which governs the indications of that safeguard to navigation, the sounding machine invented by Lord Kelvin (formerly Sir W. Thomson). To compare the graduations on Lord Kelvin's measuring scale for his tubes we would require to know the particular conditions under which the graduation was made, facts which are not known to the author. However, we may treat the subject approximately to illustrate the principle of the instrument.

The specific gravity of sea water is 1·028, which, with the barometer at 30 inches, will stand as a water barometer at the height of nearly 33 feet; therefore, since we are dealing with the depths of the sea in fathoms we may consider the pressure of one atmosphere equal to 5 fathoms of sea water approximately.

The glass tube in the sounding machine is 24 inches in length; into what length of the tube will the contained air be compressed by a depth of 5 fathoms or one atmosphere?

Here we see that the water will be pressed into the tube by the weight of two atmospheres against the elasticity of one atmosphere in the tube; therefore, to calculate the volume into which the air is compressed, we have the rule:

The volume of a gas, the temperature remaining unchanged, is inversely as the pressure put upon it.

Two atmospheres : 1 atmosphere : : 24 inches : volume.

2 : 1 :: 24 : volume,

Therefore, $\frac{1 \times 24}{2} = 12$ inches in length of the tube.

What ought to be the length of the compressed air in the tube for a sounding of 10 fathoms?

Here 10 fathoms are equal to two atmospheres, therefore the compressing force is equal to 3 atmospheres.

Hence, $3 : 1 :: 24 :$ length of air chamber,

$$\frac{1 \times 24}{3} = 8 \text{ inches approximately.}$$

We may adopt any sounding as a starting-point to obtain the scale measures of any other sounding. In the example last given we could have used the scale measure for 2 atmospheres, thus—

$$3 : 2 :: 12 : \text{length of air chamber,}$$

Therefore, $\frac{2 \times 12}{3} = 8$ inches.

What will be the length of the compressed air in the tube for a sounding of 50 fathoms?

Here we have,

$$11 : 3 :: 8 : \text{length of air chamber,}$$

Therefore, $\frac{3 \times 8}{11} = 2\frac{2}{11}$ inches.

We have only dealt with whole atmospheres, since our object has only been to illustrate the principles of the sounding-tube, but the calculations may be as readily made by taking the atmospheres and their corresponding fractions to every fathom.

For example, a fathom by our assumption is equal to $\frac{1}{5}$ of an atmosphere, that is equal to ·2. Suppose we require the length of compressed air in the tube for a sounding of 16 fathoms, we have—

$$4{\cdot}2 : 1 :: 24 : x$$

Therefore, $\frac{1 \times 24}{4{\cdot}2} = 5{\cdot}7$ inches length of air chamber.

The inverse problem may be quite as readily calculated; let the number of inches in length of the compressed air and the total length of the tube be given to find the number of atmospheres and then thence the depth of water.

Taking the last example—

We have, $5{\cdot}7 : 24 :: 1 :$ number of atmospheres,

Therefore, $\frac{24}{5{\cdot}7} = 4{\cdot}2.$

As this includes the pressure of one atmosphere on the surface of the sea, we must deduct one atmosphere to obtain the number of atmospheres in depth of water. We get therefore—

$$\text{Depth of water} = 3{\cdot}2 \times 5 = 16 \text{ fathoms.}$$

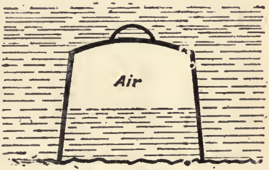
From the foregoing it will be seen that should the graduated scale of Lord Kelvin's sounding-machine be mislaid or lost, the soundings may be approximately ascertained by means of a two-feet rule, considering the atmospheric pressure as equal to five fathoms. We may, therefore, state the last rule as follows:

Divide the whole length of the sounding-tube by the length of the coloured air-chamber; the quotient will be the number of atmospheres; from which deduct one atmosphere and multiply the remainder by 5; *the result will be the sounding in fathoms nearly.*

The Diving-Bell.—The Diving-bell is a heavy metal vessel, usually prismatic or rectangular in shape, capable of sinking to any required depth mouth downwards, whereby the air in the bell is compressed into its upper part by the water rising within it while it descends. It is usually capacious enough to admit of several men descending in it and carrying on operations at the bottom.

The object of having the diving bell wider at the mouth than at the crown is to give a greater depth of air space above the surface of the water in the interior of the bell, thereby lessening the depth of water which enters it for a given pressure. Supposing for simplicity, the bell to have the same area at the crown as it has at its mouth, then the height to which the water would rise inside may be calculated by the rule given for Lord Kelvin's sounding-tubes.

FIG. 52.



Diving Bell.

If the bell is 12 feet in depth and is sunk in 5 fathoms of water, the space into which the air will be compressed will be inversely as the pressure; adding one atmosphere, supposed equal to 5 fathoms, to the depth of water gives 10 fathoms, equal to two atmospheres. We therefore divide the total internal depth of the bell by 2, which gives—

$$\frac{12}{2} = 6 \text{ feet.}$$

This is the depth of the air space in the bell; if it were sunk in 10 fathoms we would get—

$$\frac{12}{3} = 4 \text{ feet}$$

for depth of air space. Hence the obvious reason for making the diving-bell narrower at the crown.

Effect of Heat on Gases.—When heat is applied to a given mass of gas which is free to expand, its volume is increased, while its elastic force remains constant; but when it is enclosed in any vessel incapable of extension, its elastic force is increased while its volume remains constant.

It is for this reason that the tubes of the sounding-machine of Lord Kelvin should be immersed in the sea water before taking a sounding, so that the air in the tube may acquire the same temperature as the water in which the sounding is taken, and therefore give more accurate results.

The law which governs the changes of volume and of elasticity of gases due to a given change of temperature owes its discovery to Dr. John Dalton in England, followed by Gay-Lussac in France, and may be stated as follows:

A given mass of gas whose temperature is 32°, and which is allowed to expand freely under a constant pressure, on being heated to 212° receives an increase of volume which is equal to 0·366 *of its original volume; and for intermediate temperatures, and those above 212° receives an increase of volume proportional to the number of degrees above 32°.*

If we take 1000 cubic inches of common air at the temperature of 32° and heat it to 212°, it will expand into 1366 cubic inches, while its elasticity remains constant. The difference between 32° and 212° is 180°, therefore the increase of volume of the air, or any gas, for a change of 1° of temperature is equal to the 180th part of 0·366, or its volume at 32° divided by 492. If T be the temperature shown by the Fahrenheit scale, the number of degrees above 32° is T − 32°; therefore the increase of volume for temperature T is

$$= \frac{\text{volume at } 32^\circ}{492} \times (T - 32^\circ).$$

Now supposing the volume at 32° to equal 1, we get the increase of volume for temperature T equal to

$$\frac{1}{492} \times (T - 32^\circ).$$

Therefore the volume at temperature T is equal to the volume at 32° *plus* the increase of volume for the number of degrees in (T – 32°).

$$\text{Volume at temperature } T = 1 + \frac{1}{492}(T - 32^\circ).$$

$$\text{Reducing fraction} \quad = \frac{492 - 32^\circ + T}{492} \times \text{volume at } 32^\circ$$

Therefore

$$\text{Volume at } T = \frac{(460 + T)}{492} \times \text{volume at } 32^\circ \qquad (1)$$

If a mass of atmospheric air has a volume of 200 cubic inches at temperature 32°, what will be its volume at temperature 70°?

$$\text{Volume at } 70^\circ = \frac{460 + 70}{492} \times 200 = 215{\cdot}4 \text{ cubic inches.}$$

A mass of gas has a volume of 80 cubic inches at temperature 32°, what will be its volume at temperature 82°?

$$\text{Volume at } 82^\circ = \frac{460 + 82}{492} \times 80 = 88 \text{ cubic inches.}$$

If we have given the volume of a mass of gas at another temperature *t*, we get

$$\text{Volume at } t = \frac{460 + t}{492} \times \text{volume at } 32^\circ \qquad (2)$$

Dividing equation (2) by equation (1), we get

$$\text{Volume at temperature } t = \frac{460 + t}{460 + T} \times \text{volume at } T \quad (3)$$

Therefore by formula (3) we can calculate the volume which a gas will have at a given temperature when we know its volume at another given temperature, supposing the pressure or elastic force of the gas to remain constant.

If 200 cubic inches at 46° be heated to 96°, what will be its volume?

$$\text{Volume at } 96^\circ = \frac{460 + 96}{460 + 46} \text{ volume at } 46^\circ$$

$$= \frac{556}{506} \times 200 = 220 \text{ cubic inches nearly.}$$

If 180 cubic inches of air be allowed to cool down from 140° to 40°, calculate its volume.

$$\text{Volume at } 40^\circ = \frac{460 + 40}{460 + 140} \times 180$$

$$= \frac{500}{600} \times 180 = 150 \text{ cubic inches.}$$

By the formula (3) we may calculate the temperature of a gas when we have given its volume at a given temperature and its volume at an unknown temperature.

If 160 cubic inches of gas at 50° be heated until it expands to 210 cubic inches, required the temperature:

Let the required temperature be T, then

$$\text{Volume } 210 = \frac{460 + T}{460 + 50} \times 160.$$

Therefore transposing

$$T = \frac{210 \times 510}{160} - 460$$

$$= 670 - 460 = 210^\circ \text{ temperature nearly.}$$

Reversing the above example, suppose the volume to be 210 cubic inches at 210°; find the temperature at which the volume is reduced to 160 cubic inches.

$$\text{Temperature} = \frac{(460 + 210) \times 160}{210} - 460 = 50^\circ \text{ nearly.}$$

Sinking and Floating Forces of Bodies.—*If a body be heavier than the liquid in which it is immersed it will sink with a force which is equal to its weight, minus the weight of an equal bulk of the liquid.* For example, a cubic foot of iron, whose weight is equal to 475 lbs., will sink in sea water with a force of 475 – 64 lbs., equal to 411 lbs.

If the body be lighter than the liquid it will rise with a force which is equal to the weight of an equal bulk of the liquid minus its own weight. Thus a cubic foot of white fir, whose weight is 29·3 lbs., would rise in sea water with a force equal to 64 – 29·3 lbs., equal 34·7 lbs. This is the principle governing the floating power of spars, &c., dealt with in a previous article.

Both these statements may be included in the proposition:

A body when sunk beneath the surface of a liquid loses as much of its own weight as is equal to that of the liquid displaced. If a solid body floats in a liquid it displaces a bulk of the liquid whose weight is equal to its own.

Reverting to the two examples just given, a cubic foot of iron would sink with a force of 411 lbs., while a cubic foot of white fir would rise with a force of 34·7 lbs.; therefore combining the two so that the iron may not sink nor the fir rise, we find that 11·8 cubic feet of white fir attached to the iron will prevent it from sinking; that is, the weight of a cubic foot of the combined mass will equal 64 lbs.; it will therefore be indifferent, and will remain at rest at any depth below the surface.

These principles are, doubtless, well known to smugglers in planting contraband at the sea bottom.

Loss of Weight by Immersion.—A few examples may illustrate what has just been enumerated.

An iron barge weighing 24 tons is sunk, calculate the weight to be lifted in bringing her to the surface, supposing that there is no wood about her hull to assist her buoyancy.

One ton of iron contains 4·71 cubic feet; therefore the number of cubic feet in 24 tons

$$= 24 \times 4{\cdot}71 = 113{\cdot}04 \text{ cubic feet.}$$

One ton of sea water contains 35 cubic feet; therefore

$$\text{Weight of water displaced} = \frac{113{\cdot}04}{35} = 3{\cdot}23 \text{ tons.}$$

Therefore the weight to be raised is:

$$24 - 3{\cdot}23 = 20{\cdot}77 \text{ tons.}$$

Or we might have found the difference of the weights by means of their specific gravities. The specific gravity of iron is 7·6 and that of sea water is 1·028.

$$7{\cdot}6 : 1{\cdot}028 :: 24 : \text{diff. weight.}$$

$$\text{Therefore} \qquad \frac{1{\cdot}028 \times 24}{7{\cdot}6} = 3{\cdot}24 \text{ tons.}$$

And $\quad 24 - 3{\cdot}22 = 20{\cdot}76$ tons, the same as before, approx.

An anchor when in the water, supposing its weight to be $2\frac{1}{2}$ tons, loses only about $6\frac{3}{4}$ cwt. of its weight.

A boiler weighing 12 tons falls overboard and fills; what will be the strain on the tackle when recovering it?

$$7{\cdot}6 : 1{\cdot}028 :: 12 : \text{diff. weight.}$$

$$\text{Therefore diff. weight} = \frac{1{\cdot}028 \times 12}{7{\cdot}6} = 1{\cdot}62 \text{ tons.}$$

Therefore

$$\text{Strain on recovering tackle} = 12 - 1{\cdot}62 = 10{\cdot}38 \text{ tons.}$$

It is a matter of indifference at what depth a body may be sunk, its weight will remain constant whether at one fathom below the surface or a thousand fathoms below the surface. It is the pressure only which is affected by the depth, and that acts equally in every direction at any given point.

Pressure of Water on a Ship's Bottom.—The pressure of water on a ship's bottom will vary as the depth and will press equally in every direction at that depth. For example, the pressure upwards upon a ship's bottom at 24 feet below the surface of the sea will be equal to the weight of 24 cubic feet of sea water upon the square foot of surface, therefore—

$$\text{Pressure on square foot} = 24 \times 64 = 1536 \text{ lbs.},$$

since a cubic foot of sea-water weighs 64 lbs.

We may also find the pressure upon a square inch of surface at 24 feet depth. A cubic inch of sea water weighs 0·037 lb., or a column 1 square inch in cross section and 1 foot long weighs 0·444 lb.

Therefore,

$$\text{Pressure on square inch} = 24 \times \cdot444 = 10\cdot656 \text{ lbs.}$$

In blowing out boilers the engineer has to consider the ship's draught in order to regulate the pressure of steam necessary to fill the boiler at a pressure somewhat higher than the pressure of water outside *plus* one atmosphere, when the whole of the water has been driven out. Suppose it is required to blow out the boilers through a valve at 24 feet below the surface of the sea, and assuming an atmosphere to equal 15 lbs. per square inch, we get the pressure of the expanded steam

$$= 10\cdot656 + 15 = 25\cdot656 \text{ lbs.}$$

The necessary pressure would therefore have to exceed this in actual practice.

Pressure of Water on Bulkheads.—*The pressure of water on a vertical surface is equal to the area of the surface in square feet multiplied by* 64, *and this product multiplied by the depth below the surface of the water, of the centre of gravity of the surface pressed.*

Example I.—A ship's bulkhead is 40 feet in breadth, and there are 15 feet of water in the hold; calculate the pressure of water on the bulkhead, supposing the ship to be flat-bottomed and wall-sided, in which case the centre of gravity of the bulkhead would be $7\frac{1}{2}$ feet below the surface of the water.

For the area of the surface pressed we get

$$40 \times 15 = 600 \text{ square feet.}$$

Therefore,

$$\text{Pressure on bulkhead} = 600 \times 64 \times 7\cdot5 = 208000 \text{ lbs.}$$
$$= 128\cdot57 \text{ tons.}$$

Example II.—A ship is 44 feet beam, and there is a depth of 24 feet of water in the hold pressing against the bulkhead, which has the form of a parabola; calculate the pressure of water.

The area of a parabola is equal to $\frac{2}{3}$ the product of the height by the breadth.

Therefore,

$$\text{Area of bulkhead} = \tfrac{2}{3} \times 44 \times 24 = 704 \text{ square feet.}$$

The centre of gravity of a parabola is $\frac{2}{5}$ of its vertical height from the base.

Therefore centre of gravity of bulkhead $= \frac{2}{5}$ of $24 = 9{\cdot}6$ feet below the surface of the water.

Therefore,

$$\text{Pressure of water on bulkhead} = 704 \times 64 \times 9{\cdot}6 = 432537{\cdot}6 \text{ lbs.}$$
$$= 193 \text{ tons nearly.}$$

This is the pressure of water against the bulkhead, or against each bulkhead, between which the water is contained; and the pressure will be the same whether they are separated by a distance of 1 foot or by half the length of the ship, since the pressure of water upon a vertical surface is dependent upon its depth only. For instance, the whole breadth or length of the Atlantic Ocean is balanced by the water in the lock of a dock or canal, so long as the water within the lock has the same level as the ocean without; indeed the length of the lock might be reduced to 1 inch with the same result.

Example III.—The collision bulkhead of a vessel is in the form of an inverted triangle, therefore its area is equal to half the product of its depth by its greatest breadth. The breadth is 22 feet and the depth 18 feet; calculate the pressure against it when 18 feet of water bears against it.

$$\text{Area of bulkhead} = \frac{18 \times 22}{2} = 198 \text{ square feet.}$$

As the centre of gravity of a triangle is $\frac{1}{3}$ of its height from the base we get the centre of gravity of the wet surface of the bulkhead equal to 6 feet below the water surface.

Therefore,

$$\text{Pressure on bulkhead} = 198 \times 64 \times 6 = 76032 \text{ lbs.}$$
$$= 34 \text{ tons nearly.}$$

Example IV.—A ship has a semicircular bulkhead of 40 feet in breadth, and a depth of 20 feet of water bears against it; calculate the pressure against it.

$$\text{Area of bulkhead} = \frac{40^2 \times {\cdot}7854}{2} = 800 \times {\cdot}7854$$
$$= 628{\cdot}32 \text{ square feet.}$$

The distance of the centre of gravity of a semicircle from its base is equal to 4 times its radius divided by 9·4248.

Therefore,

$$\text{Centre of gravity} = \frac{4 \times 20}{9{\cdot}4248} = 8{\cdot}488 \text{ feet below water surface.}$$

Therefore,

$$\text{Pressure on bulkhead} = 628{\cdot}32 \times 64 \times 8{\cdot}49 = 341323 \text{ lbs.}$$
$$= 152{\cdot}4 \text{ tons.}$$

Pressure of Water in Ballast Tank.—The pressure in lbs. upon the crown of a ship's water-ballast tank when the filling-cocks are open and the tank is full will be equal to the depth of the crown of the tank below the sea surface in feet, multiplied by 64, and by the area of the tank crown in square feet.

EXAMPLE.—The top or crown of a water-ballast tank is 20 feet below the sea surface when full, and has an area of 1000 square feet. Calculate the pressure upon the crown of the tank.

$$\text{Pressure} = 20 \times 64 \times 1000 = 1280000 \text{ lbs.} = 571{\cdot}4 \text{ tons.}$$

When the filling-cock is open after the tank is full, the water in the air-pipe rises to the level of the sea surface outside the ship. Now suppose the filling-cock is shut, and that the surface of the water in the air-pipe is 4 feet below the deck. If we now fill the air-pipe with water to the level of the deck, we get a head of water equal to 24 feet, *i.e.*, the difference between the surface of the water in the pipe and the crown of the tank upon which the pressure is exerted.

Therefore

$$\text{Pressure on crown} = 24 \times 64 \times 1000 = 1536000 \text{ lbs.}$$
$$= 685{\cdot}7 \text{ tons.}$$

Now if the bore of the air-pipe is 1 inch, which is usually about its diameter, the 4 feet which have been filled up will contain about 38 cubic inches of water, or about 4 cubic inches more than a pint, equal in weight to about 1 lb. 5 oz., and this small quantity of water increases the pressure upon the crown of the tank from 571·4 tons to 685·7 tons, the difference between which is 114·3 tons.

We will show by another example how the pressure of the water upon the bottom of the tank greatly exceeds the weight of the water it contains.

In the preceding example suppose the depth of the tank to be 3·5 feet and the ship's bottom to be horizontal, the tank would therefore contain 100 tons of water. This would give a pressure upon the bottom of the tank of 671·4 tons when the tank was full with the filling-cock open; and when the air-pipe was filled up to the deck with the filling-cock shut, this pressure would be increased to 785·7 tons. Now the weight of the water in the tank is 100 tons, therefore the pressures on the bottom of the tank exceed the weight of water by 571·4 tons and 685·7 tons respectively.

As another example.—The crown of a ship's ballast tank has an area of 1800 square feet, and is 11½ feet below the surface of the sea when the tank is full. Calculate the pressure on the crown of the tank when the filling-cock is open with the tank full.

$$\begin{aligned}\text{Pressure on crown} &= 1800 \times 11{\cdot}5 \times 64 = 1324800 \text{ lbs.}\\ &= 591{\cdot}6 \text{ tons.}\end{aligned}$$

The tank contains 180 tons of water, therefore the pressure on the crown exceeds the weight of water by 591 – 180 = 411 tons.

Velocity of Water through a Small Hole.—The velocity of water through a small hole in a ship's side or bottom is approximately proportional to the square root of the product of the depth of the hole below the sea surface and 64, when the entrance of the water is only opposed by the free air in the hold; when the water within the ship is above the hole the velocity will be equal to the square root of the product of the difference of level between the sea surface and the water inside the ship into 64. Making the calculation for 1, 4, 9, 16, 25, and 36 feet we have:

Velocity at depth of 1 ft. = $\sqrt{1 \times 64} = 8$ ft. per second approximately.
" " 4 ft. = $\sqrt{4 \times 64} = 16$ " " "
" " 9 ft. = $\sqrt{9 \times 64} = 24$ " " "
" " 16 ft. = $\sqrt{16 \times 64} = 32$ " " "
" " 25 ft. = $\sqrt{25 \times 64} = 40$ " " "
" " 36 ft. = $\sqrt{36 \times 64} = 48$ " " "

If we divide all these velocities by 8 we get the velocity at

$$\left.\begin{array}{lrl} \text{depth of} \ldots & 1 \text{ foot} & = 1\\ \text{"} \ldots & 4 \text{ feet} & = 2\\ \text{"} \ldots & 9 \text{ "} & = 3\\ \text{"} \ldots & 16 \text{ "} & = 4\\ \text{"} \ldots & 25 \text{ "} & = 5\\ \text{"} \ldots & 36 \text{ "} & = 6 \end{array}\right\} = \text{Relative velocities.}$$

We thus see that the velocities vary as the square root of the depths; for instance, at a depth of 9 feet below the surface the water will run in three times as fast as it would at a depth of 1 foot below the surface, and so on; for any depth whatever we have only to extract the square root of that depth to know how much faster the water flows into the ship than it would do at 1 foot depth.

It has often been a matter of surprise to sailors to see what a small rent in a plank in the bilge has been the sole cause of their hourly attention to the pumps to keep their vessel free of the inflowing water, especially when their vessel was well known to be a very dry one, and regained her character as such when this defect in her planking was made good.

Floating Ice.—*If a homogeneous body floats in a liquid, its whole volume will be to that of the part immersed in the inverse ratio of the specific gravities of the body and of the liquid.*

Whole volume : part under water :: SG of water : SG of body.

For an example we may take ice and calculate how much of the whole bulk of a mass of ice is under water; suppose we call the whole volume or bulk of ice 1, then by the proportion just stated, and the specific gravities of sea water and ice, respectively equal to 1·028 and ·930.

$$1 : \text{part under water} :: 1{\cdot}028 : {\cdot}930.$$

Therefore,

$$\text{Part under water} = \frac{{\cdot}930}{1{\cdot}028} = {\cdot}905$$

If we suppose the mass of ice to contain 1000 cubic feet there would be 905 cubic feet under water, therefore the number of cubic feet above water would be $1000 - 905 \times 95$ cubic feet.

Therefore the proportion of the part of a mass of ice above water to that below water is as 95 to 905. With these two constants we may find the depth of an iceberg below water, when we know the height of the part above water, provided its sides are vertical from top to bottom; otherwise we can only find the ratio of the part below water to that above in volume.

An iceberg having vertical sides floats with a height of 80 feet above water; calculate its depth below water.

$$95 : 905 :: 80 : \text{depth}.$$

Therefore,

$$\frac{905 \times 80}{95} = 762 \text{ feet}.$$

$$\text{Or dividing 905 by 95 we get } \frac{905}{95} = 9{\cdot}5.$$

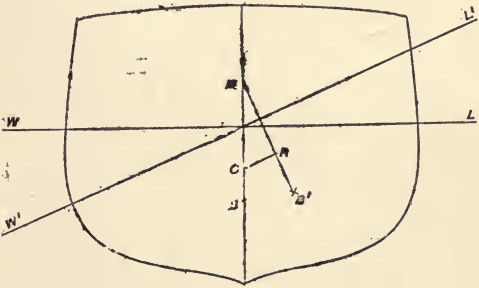
A constant by which we have only to multiply the height of the iceberg above water to get its depth below water; thus $9{\cdot}5 \times 80 = 760$ feet.

Floating Timber.—It is well known that a plank of wood will float on its flat side only, unless it is heavily loaded on one edge, and even should its centre of gravity not be midway between its two flat surfaces it will have a stable flotation on either of its flat sides. As we increase the thickness of the plank relative to its breadth so the weight necessary to float it on its edge, or turn it over altogether becomes less until the thickness becomes equal to the breadth, when supposing this log to be of uniform density and having its centre of gravity situated on its central axis, it will float indifferently on any one of its four sides, and its capsizing weight will be a minimum; since a small heel given to the spar will enable the centre of gravity of the displaced water to pass from a point vertically below the log's centre of gravity to a point at one side of it, from whence a line drawn vertically to the surface of the water acts at a point on the log's vertical fore-and-aft midship plane below the centre of gravity and turns it over.

A round spar of uniform density or a uniform cylinder has no stability of flotation, since a section of the displaced water has a constant uniform figure; therefore the centre of gravity of the spar or cylinder is always in the same vertical line as the centre of gravity of the displaced water. This is a stability of indifference; hence round or cylindrical bodies must be heavily ballasted to prevent them from floating in any but the desired position.

Stability of Ships.—When a vessel, such as a ship, floats upright, the centre of gravity G of the ship, and the centre of

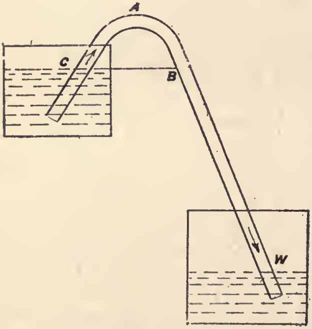
FIG. 53.



gravity B of the displaced water, called *centre of buoyancy* and *centre of displacement,* will both be situated in the same vertical fore-and-aft plane. Let WL (Fig. 53) be the water line when the ship is upright, and W′L′ the water line when the vessel is heeled over at a small angle. In the upright position, the centre of buoyancy B, and the centre of gravity of the ship are both in the vertical line BGM ; but when heeled over, the centre of buoyancy moves outwards towards the low side and takes up the position B′; therefore B′ and G are no longer in a vertical line. Hence the force at B′ acting vertically upwards, perpendicular to the water line W′L′ meets the vertical fore-and-aft plane in M ; this point is called the *metacentre* and its effective lever arm is GR, at which the buoyancy force acts perpendicularly. When M is above the ship's centre of gravity G the force B′M tends to restore the ship to an upright position round G as a centre. When M is below G at any angle of heel, then the force B′M helps to turn the ship over. Therefore when M is above G the vessel is stable; when below G, unstable ; and when it coincides with G, the stability is one of indifference, since there is a total absence of both righting and heeling force, with the result that the ship will remain at rest in any position. For the calculations on Stability of Ships the reader is referred to the volume in this Series, entitled "Know your own Ship," wherein the subject of "Stability and Strength of Ships" is practically dealt with.

The Syphon.—The syphon (Fig. 54) consists of a bent tube, with one leg longer than the other. It is used for emptying the liquid contents out of one vessel into another by conveying it over the edge of the vessel to be emptied. To use it, put the short leg into the liquid to be drawn off and suck the air out at the end of the long leg until the liquid flows ; it will now continue to run until the vessel is emptied, provided that the end of the short leg is always kept below the surface of the fluid. The principle of the syphon is dependent on the atmospheric pressure, and it will not act if the highest point A of the syphon is more than 34 feet above

FIG. 54.



the surface of the liquid C when the barometer stands at 30 inches.

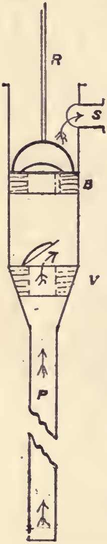
If the height A be less than 34 feet above C, the pressure at A acting against the column in the long leg AW is equal to the atmospheric pressure *minus* the weight of the column in the short leg, while the pressure of the long leg acting at A is equal to the atmospheric pressure, *minus* the weight of column in the long leg; the column of liquid in the long leg is therefore forced downwards by this difference of pressure.

The velocity of the water through the syphon will be proportional to the square root of the difference between the levels of C and W.

Use of the Syphon.—The syphon might be much more frequently used on board ship than it is, since it may be made out of a piece of lead pipe by the carpenter and be an advantageous substitute for the wasteful dipper or tin pump in drawing water from the deck tanks and casks. It would also be convenient for emptying the oil casks which come on board to fill the lamp-room tanks. In this latter use, to avoid the unpleasantness of sucking the oil through the syphon to start it, pass a piece of spun yarn or marline through a cork and knot it about two inches from the cork; make fast the other end to a long piece of stick or iron rod of any kind; insert this cork in the short leg of the syphon, turn the long leg, mouth upwards, and fill it with oil; put a cork in to keep it from running out; lay the stick or rod which is fast to the cork, alongside the short leg, turn the syphon over and insert the short leg and stick into the bung-hole of the cask to be emptied; when the syphon is in position, push down the stick, which will pull the cork out; then pull the cork out of the long leg and the oil will begin to run; it may be stopped at any time by either putting the finger over the mouth or inserting the cork.

The Suction-Pump.—The common suction-pump (Fig. 55) has a cylinder BV in which the bucket B works up and down; V is the lower box, which is fixed in its seat. The bucket is packed with leather and has a leather flap-valve on its upper side usually loaded with lead. The lower box is packed with white hemp strands or rounding, and well tallowed to make it air-tight; it also has a leather flap-valve. R is the bucket rod which is attached to the levers or crank which works the pump; P is the suction-pipe which descends to the water in the well and has a rose fitted to its lower end to prevent substances from entering the suction-pipe; S is the spout through which the water is delivered. When B is raised its valve closes and a vacuum is created in the chamber BV; the air in the suction-pipe expands and opens the valve V, again filling the chamber BV, when B again descends the air rushes through its valve while V is closed by the compression; as the air in the suction pipe expands through V the water in the well follows it up, maintaining it at atmospheric pressure. When all the air has been pumped out the water flows, so that the common pump has to serve both the purposes of an air and a water-pump. If the depth of the water's surface below the bucket exceeds 32 feet, the water will not flow, since the pressure of the atmosphere is only capable of supporting a column of about 32 feet of sea water. Hence in large ships having deep holds the pumps are fitted to deliver on the main deck. The weight of water which the bucket lifts is the weight of a column of water from the bucket to the surface of the water in the well, having the same sectional area as the bucket.

Fig. 55.



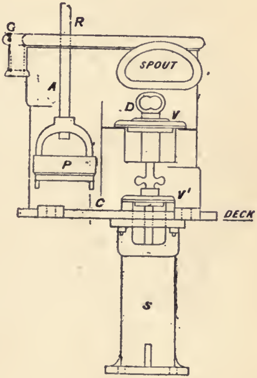
Suppose the diameter of the bucket to be 6 inches and the column of water 27 feet, then we get the weight of—

$$\text{Water} = 0{\cdot}5^2 \text{ foot} \times {\cdot}7854 \times 27 \times 64$$
$$= {\cdot}7854 \times 27 \times 16 = 339{\cdot}29 \text{ lbs.}$$

$0{\cdot}5^2$ is the square of the diameter, which, multiplied by ·7854, gives the area of section in square feet; this multiplied by 27 gives the number of cubic feet of water; this again multiplied by 64 lbs. gives the weight of water in the pump.

Redpath's Pump.—The accompanying diagram (Fig. 56) represents Redpath's Pump, which consists of two chambers. In the chamber A a solid piston P works; in the chamber D are two plunger valves, V and V′. When the piston P descends it forces the air through the channel C into the valve chamber, when the valve V rises and allows the air to escape into the delivery chamber, while the valve V′ is pressed tightly down on the suction-pipe S. When the piston P is raised the valve V is pressed tightly down on its seat, while the valve V′ is raised by the air in the suction-pipe S, which fills both chambers of the pump, and is expelled through V by the next down stroke of the piston, and so on, until the water flows. The piston P is packed with sennit, well greased; and fits air-tight in the chamber A; the valves V and V′ are fitted with india-rubber washers under the flanges, which make them air-tight in their seats. These plunger valves are perfectly free, and can be readily lifted out by hand, since they are conveniently within reach, being above the deck in the chamber D. Hence any derangement caused by pieces of rope yarn, or chips of wood stopping the plunger from returning to its seat can be at once removed. Coffee, rice, beans, grains, &c., may all be pumped out with the water without the least danger of these pumps becoming choked. In the author's experience, a very considerable quantity of a cargo of coffee was pumped out during the voyage without these pumps ever choking. Two pumps are fitted at the fife-rail by the main-mast, and may be worked one at a time or both together. A crank shaft lies across the fife-rail, and has two fly-wheels fitted to it; into these the handles are shipped. The piston-rod R works in a guide from G; a connecting-rod couples the rod R to the crank.

Fig. 56.



The theoretical purchase of Redpath's pump is to the power applied to the handles as the radius of the handles is to the radius of the crank.

Example.—The radius of the handles is 14 inches; the radius of the crank is 3 inches; the piston is 6 inches in diameter, and the suction-pipe has the same bore. The well is 24 feet below the top stroke of the piston. Calculate the power to work the pump.

We must first calculate the weight of a column of sea water, 24 feet in length and 6 inches in diameter. 6 inches = ·5 of a foot. The area of a circle = square of the diameter multiplied by ·7854.

Therefore,

Area of suction-pipe $= \cdot 5^2 \times \cdot 7854 = \cdot 19625$ square foot.

Depth of well is 24 feet; therefore,

Cubic feet in column of water $= 24 \times \cdot 19625 = 4 \cdot 71$.

A cubic foot of sea water weighs 64 lbs.

Therefore,

Weight of water to be raised $= 4{\cdot}71 \times 64 = 301{\cdot}4$ lbs.
Radius of handle : rad. of crank :: $301{\cdot}4$: power.
Or, 14 : 3 :: $301{\cdot}4$: power.

Therefore,

$$\text{Power on handles} = \frac{3 \times 301{\cdot}4}{14} = 64{\cdot}5 \text{ lbs.}$$

If we allow 40 per cent. of the power applied to be lost by friction, we get the practical working power

$$= \frac{64{\cdot}5}{{\cdot}6} = 107{\cdot}5 \text{ lbs.}$$

Which would require 4 men exerting a force of 27 lbs. each.

CHAPTER XIII.

MOTION AND VELOCITY.

Motion means a change of position, and is therefore a condition opposite to being at rest.

Velocity is the speed with which a body is moving, and may be either uniform or variable. It is uniform when equal distances are passed over in equal times; variable when unequal distances are passed over in equal times. The speed or velocity of a ship is usually variable. Thus, she may at one time have a speed of 9 knots, and at another time a speed of 11 knots; therefore, if we find that in an interval of twenty-four hours 240 miles have been traversed, we get an average speed of 10 knots per hour by dividing the distance by the time. In the absence of sights to find the ship's position at the end of the twenty-four hours, the average speed will be approached more and more closely the more frequently the log is hove. But the velocities we are now about to deal with must be treated by a more refined process than the speed of a ship.

The *British units of measure* for velocities are 1 foot in distance and 1 second in time; therefore, to find the velocity with which any body is moving, we divide the distance in feet by the number of seconds the body has taken to move through the given distance; this will give the velocity per second when the motion is uniform, or the average velocity per second when the motion is variable. Thus, a train is observed to move over a mile in 60 seconds; therefore,

$$\text{Velocity} = 5280 \text{ feet} \div 60 = 88 \text{ feet per second.}$$

If we reduce the interval to 10 seconds, and then find that the train moved over 880 feet in that time, and from observations at other times find that 880 feet were passed over in each 10 seconds, we shall be justified in concluding that the train was moving with a uniform velocity of 88 feet per second, since in such a short interval as 10 seconds there would be little or no change in the motion of a train. In the variable velocity of a ship, we dealt with an intermittent motion; but variable velocities may be either continually decreasing, or continually increasing, such as the velocities produced by the action of *gravitation.* For instance, a stone dropped from a height of 16 feet will fall with an increasing velocity until it reaches the ground with a velocity of 32 feet per second. If, on the other hand, the stone were thrown upwards with a velocity of 32 feet per second, it would ascend with a continually decreasing velocity until it reached the height of 16 feet, when it would begin to descend and again reach the ground with the same velocity as that with which it was started.

Acceleration.—*Acceleration* is the rate of change which takes place in a variable velocity, and may be either a rate of increase or a rate of decrease, as has just been shown in the example given above. The acceleration of gravity varies for different places on the earth's surface. Thus, in the latitude of London it is 32·2 feet per second; at the equator it is 32·09 feet per second. The acceleration of gravity is a uniform acceleration, which increases the velocity of a body wholly under its action by 32 feet every second (neglecting the fraction). For example, when a body falls *in vacuo* from a state of rest, in the first second it will have acquired a velocity of 32 feet; in the next second its velocity will be increased to 64 feet per second; in the third second to 96 feet per second; and in the fourth second to 128 feet per second, and so on continually.

Mass constant.—The *mass* of a body is the quantity of matter which it contains.

Weight due to Gravity.—The *mass* must not be confounded with the *weight* of a body, because the weight of a body depends on whether it is at London or at the Island of Ascension. If a body were weighed at these two places on a pair of scales, or balance, the same weight would be shown at both places, since the body and counterpoise would be equally affected by gravity. But if it were weighed in a spring balance, it would weigh less at the Island of Ascension than at London, because the force of gravity is less near the equator than in high latitudes. A body which weighs a pound on the surface of the earth, where gravity is 32·2 feet per second, would weigh on the surface of the sun about 29½ lbs., where the acceleration of gravity is about 949·9 feet per second, and yet it would always have the same mass. The weight of a body at any place, divided by the acceleration of gravity at that place, is the number of units which represents the mass of the body. The weight of a body in the latitude of London is 40 lbs.; divide this by the acceleration of gravity, 32·2, for that latitude, and we get $40 \div 32{\cdot}2 =$ the mass $= 1{\cdot}24$. The same body would weigh at Ascension 39·86 lbs., but the acceleration of gravity there is only 32·09 feet per second, from which we get the mass

$$= 39{\cdot}86 \div 32{\cdot}09 = 1{\cdot}24,$$

which is identical with the former, to the second place of decimals. The weight of the same body on the sun would be 1180·0 lbs., where the acceleration of gravity is 949·9, whence we get the mass

$$= 1180{\cdot}0 \div 949{\cdot}9 = 1{\cdot}24$$

Did it ever occur to the sailor that he got more than his prescribed allowance of salt meat within the tropics, since it is always weighed with a spring balance tested in higher latitudes? a fact which would reduce a tierce of beef, 336 lbs. weighed in London, to 334·69 lbs. when weighed on the equator by a spring balance.

Momentum.—The *momentum* of a body is its mass multiplied by its velocity. The weight of a body in the latitude of London is 64·4 lbs.; therefore its mass is 64·4 ÷ 32·2 = 2. Suppose it to be moving with a velocity of 60 feet per second, then its momentum is 2 × 60 = 120 units; *i.e.*, a force of 120 lbs. acting for 1 second would produce in the body a velocity of 60 feet per second. While moving with this velocity an opposing force of 120 lbs. acting for 1 second would bring it to rest; or an opposing force of 1200 lbs., acting through one-tenth of a second would also bring it to rest; so would the velocity of 60 feet per second be produced by a force of 1200 lbs. acting upon the same body during one-tenth of a second. A railway truck weighs 10 tons, its momentum—neglecting the friction of the rails and wheels—would be, when moving with a velocity of 1 foot per second,

$$= 1 \times \frac{209 \text{ cwt.}}{32{\cdot}2} = 6{\cdot}21 \times 112 \text{ units};$$

i.e., a force pushing the truck for 1 second must be equal to 6·21 cwt. to produce a velocity of 1 foot per second.

Warping a Ship.—Suppose a ship of 5000 tons displacement to be lying in still water in a calm, so that we may consider her free from the action of any external forces, ~~such as those of the wind, current, and tide, and neglecting skin friction in the water,~~ we desire to know what force acting for 1 second will produce a speed of 2 feet per second in the ship.

Here we have given the weight and velocity to find the momentum,

$$\text{Momentum} = \text{Mass} \times \text{velocity}.$$

But $\text{Mass} = \text{weight} \div \text{force of gravity}.$

~~Therefore,~~ So

$$\text{Momentum} = \frac{\text{weight} \times \text{velocity}}{\text{force of gravity.}}$$

10000
96
11020
3/24

THEREFORE

~~Hence,~~ $$\text{Force} = \frac{5000 \times 2}{32} = 312{\cdot}5 \text{ tons.}$$

From this we can find the force for the ship moving with a speed of one inch a second, for we have simply to divide 312·5 tons by the number of inches in two feet, therefore,

$$\text{Force} = 312{\cdot}5 \div 24 = 13$$ TONS ~~nearly~~,

i.e., a force of 13 tons acting upon the ship for one second would produce a velocity of one inch per second; since the power applied to warps in moving ships does not usually exceed 2 to 3 tons, we will take 2 tons as the strain which the winch ~~or capstan~~ exerts on the warp; from which we may ascertain how long a tension of 2 tons must be maintained on the warp to produce a speed of 1 inch in a second of time by dividing the momentum at that speed by 2; therefore 13 ÷ 2 = 6·5 seconds, the time during which a force of 2 tons would have to act to produce a speed of 1 inch per second. It will thus be seen that the force necessary to move a ship through smooth water in the absence of wind or other external forces above the water's surface may be reduced indefinitely so long as the time of its action is indefinitely increased or extended.

The problem of finding what force will produce a given velocity in a body of given weight, uninfluenced by other forces, may be stated as follows :—

$$32 : \text{velocity} :: \text{weight of body} : \text{momentum}.$$

Therefore,

$$\text{Momentum} = \frac{\text{weight of body} \times \text{by velocity.}}{32}$$

which is identical with the formula already used.

A ship of 4000 tons displacement has a velocity of 3 feet per second—nearly 2 knots an hour—what force acting for 1 second would be necessary to produce this velocity? also, supposing this velocity to be produced by heaving on a warp with a constant force for a period of 5 minutes; what must be the strain constantly maintained on the warp?

We will first find the force which, acting for 1 second, would produce the given velocity.

$$\text{Force} = \frac{4000 \times 3}{32} = 375 \text{ tons.}$$

Since the velocity of 3 feet per second may be produced by heaving on the warp for the period of 5 minutes, we get the strain which must be kept constantly on the warp for that length of time.

$$= 375 \text{ tons} \div 300 \text{ seconds, therefore,}$$

$$\text{Strain on warp} = \frac{375}{300} = 1{\cdot}25 \text{ tons.}$$

Strain on a Ship's Cable while Riding at Anchor.—*To find the strain upon a ship's cable when anchored in a tide-way or current and lying tide-rode.* We must first find the area of the surface of the bows upon which the tide acts.

Let b = beam of the ship.
d = draught of water.
a = the mean angle which the bows make with the fore-and-aft line.
S = surface of the bows in square feet.
W = weight of a cubic foot of sea water.
g = force of gravity = 32.
m = momentum of a cubic foot of water.
R = resistance or strain on the cable.

We get for the area of the bows

$$S = d\, b \text{ cosec. } a. \tag{1}$$

We next find the momentum of a cubic foot of sea water having velocity of v feet per second.

$$m = \frac{W}{g} \times v. \tag{2}$$

Therefore, the momentum of the whole body of water acting upon the bows is equal to the product of equations (1) and (2).

$$S\, m = d \times b \text{ cosec. } a \frac{W}{g} \times v. \tag{3}$$

But since the tide or current strikes the bows at an angle equal to the angle a—because its motion is parallel to the ship's fore-and-aft line—we must resolve the total momentum of the water into its component, acting against the ship parallel to her keel. From the chapter on the pressure of water on a ship's bows we get for the fore-and-aft component, the equation

$$\text{Fore-and-aft force} = \text{vel. of stream} \times \sin.^2 \phi,$$

substituting R for fore-and-aft force, S m. for vel. of stream and a for ϕ, we get

$$R = S\, m \times \sin.^2 a.$$

But S m in equation (3)

$$= d \times b \text{ cosec. } a \frac{W}{g} v$$

Therefore $$R = d \times b \text{ cosec. } a \frac{W}{g} v \sin.^2 a$$

But $\text{cosec. } a = \frac{1}{\text{sin. } a}$ therefore

$$R = d \times b \frac{W}{g} v \text{ sin. } a.$$

Hence the rule to find approximately the strain on the cable when riding in a tide or stream, neglecting skin friction:

Multiply together the draught of water, beam of ship, velocity of tide in feet per second, weight of a cubic foot of sea water, sine of the angle which the bows make with the fore-and-aft line, and divide the product by 32. The result will be the resistance or strain on the cable in lbs.

For example, a ship has 38 feet beam, 20 feet draught, angle the bows make with the fore-and-aft line 20°, and is lying tide-rode in a 6-knot tide or stream. Find the strain on the cable, neglecting skin friction.

We require the velocity of the tide in feet per second, therefore

$$\text{Velocity of tide} = \frac{6080 \times 6}{3600} = 10{\cdot}14 \text{ feet.}$$

Hence by the rule,

$$\text{Strain on cable} = \frac{20 \times 38 \times 10{\cdot}14 \times 64 \times {\cdot}342}{32}$$

Where ·342 is the natural sin. of 20°.

Reducing, we get

$$\begin{aligned}\text{Strain on cable} &= 760 \times 10{\cdot}14 \times 2 \times {\cdot}342 \\ &= 5271{\cdot}18 \text{ lbs.}\end{aligned}$$

$$\text{Or in tons} = \frac{5271{\cdot}18}{2240} = 2{\cdot}35 \text{ tons weight.}$$

The actual strain upon the cable will be in excess of this, owing to the skin friction along the ship's sides and bottom, which has been entirely neglected here. However, the investigation shows how a comparatively small force will maintain or hold the ship in position when at anchor in a strong tide and in smooth water while tide-rode. When the ship is sheered the strain on the cable will be increased and the broader the sheer the greater will be the strain, since the tide will strike upon a much greater surface. All external forces above the water, such as the wind acting upon the spars, rigging, and hull of the ship have been disregarded.

A Ship's Momentum under Sail.—A sailing ship is running

~~with square yards~~ at a speed of 10 knots under topgallant-sails, top-sails, and fore-sail on the fore-mast; topgallant-sails and top-sails on the main-mast; and top-sails only on the mizen-mast. The total area of sail on the fore-mast is 10301 square feet, and on the main and mizen-masts 10571 square feet. The displacement of the ship is 4000 tons.

The wind is blowing fresh and suddenly chops right ahead taking the ship flat aback with an average pressure of 4 lbs. on each square foot of sail. How long will this force take to stop the ship's way, neglecting the skin friction of the water?

Here we get the total sail area $= 10571 + 10301$.

$$= 20872 \text{ square feet.}$$

Therefore

$$\text{Total wind pressure} = 20872 \times 4 = 83488 \text{ lbs.}$$

Or expressed in tons

$$83488 \div 2240 = 37{\cdot}3 \text{ tons.}$$

We must now find the momentum of the ship at a speed of 10 knots.

Now 1 knot = 6080 feet; therefore $6080 \times 10 = 60800$ feet per hour, which we divide by the number of seconds in an hour to get the ship's velocity per second, therefore

$$\text{Velocity per second} = \frac{60800}{60 \times 60} = 16{\cdot}8 \text{ feet.}$$

As the momentum of a body is equal to the product of its mass and velocity, we get

$$\text{Momentum of ship} = \frac{4000}{32} \times 16{\cdot}8 = 2100 \text{ tons.}$$

Now, 2100 tons is the force which, acting during one second, would create a velocity of 16·8 feet in the same time; but the same velocity may be created by a smaller force acting during a longer time; and since we have the momentum of the ship and the force of the wind acting in opposition to it, we get

$$\text{Time of stopping ship's way} = \frac{2100}{37{\cdot}3} = 56{\cdot}3 \text{ seconds.}$$

The yards being square the sails would not have any turning power; therefore the helm would equally turn the ship's head either way and there would be plenty of time to fill the yards on either tack before she had lost her way. In a ship caught flat aback with the yards braced up the conditions are entirely altered, as not only the fore and aft sails, but the square sails being dragged forward by the head-stays while the jib-boom tends to lag behind the ship's head. At the ship's stern the spanker-boom if hauled amidships with a single sheet up and down, is very liable to carry something away, such as the topping-lift, or the sheet itself, when the ship is pitching heavily.

In discharging cargo in a roadstead while the ship is rolling an extra weight is thrown upon the slings every time the ship rolls away from the side to which the sling is hanging. Let us suppose, for example, that a 3-ton boiler is hanging over the ship's side and that she rolls away from it with an acceleration of 6 feet per second vertically upwards. We get for the force to give it this acceleration:

$$\text{Force} = \frac{60 \times 6}{32} = 11\tfrac{1}{4} \text{ cwts.}$$

But the strain on the slings is equal to the weight added to the above force.

Therefore

$$\text{Strain on slings} = 60 + 11\tfrac{1}{4} = 71\tfrac{1}{4} \text{ cwts.}$$

From this it is obvious that the difference of strain upon the slings due to the ship rolling is equal to $22\frac{1}{2}$ cwts.

A hydraulic crane raises a sling of cargo weighing 30 cwts. with an acceleration of 5 feet per second. Find the strain on the slings.

$$\text{Strain on slings} = \frac{30 \times 5}{32} + 30$$

$$= 4\tfrac{11}{16} + 30 = 34\tfrac{11}{16} \text{ cwts.}$$

And supposing the sling is lowered with an acceleration of 10 feet per second, what would be the strain on the slings.

$$\text{Strain on slings} = 30 - \frac{30 \times 10}{32}$$

$$= 30 - 9\tfrac{3}{8} = 20\tfrac{5}{8} \text{ cwts.}$$

This gives for the above rates of hoisting and lowering a difference of strain on the slings of $14\frac{1}{16}$ cwts.

It may often be observed that when a hydraulic crane is suddenly stopped during the process of a rapid hoist, the sling of cargo owing to the velocity it has acquired, continues its upward motion after the crane has ceased to hoist and again descends through a few inches with a jerk which communicates a vibration to the jib of the crane.

Falling Bodies.—When a body is allowed to fall freely *in vacuo* from a state of rest it will descend through a distance of 16 feet in the first second of time and acquires a velocity of 32 feet in the same time, and this velocity will increase at the rate of 32 feet per second for each successive second during which the body is falling freely; this increase of velocity is called the *acceleration of gravity* and is represented in works on mechanics by g. The formulæ for falling bodies are, where v represents the velocity in feet, t the time in seconds, d the vertical distance in feet, $g = 32$ feet.

$$v = gt\ (1),\ d = \tfrac{1}{2}gt^2\ (2),\ v^2 = 2gd\ (3).$$

If in equation (2) we make $t = 1$ second, then $\frac{1}{2}g \times 1^2 = d$, the height fallen through in 1 second = 16 feet. Now this is equal to half the velocity acquired in 1 second, and from equation (1) when $t = 1$ second, the velocity is equal to $g = 32$ feet.

The above formulæ may be written:

Velocity acquired = 32 × seconds. (1)
Distance fallen through = 16 × (seconds)². (2)

The third formula gives the velocity independent of the time, when the distance fallen through and force of gravity are known.

Velocity = square root of (64 × distance). (3)

From equation (2) we get the distance fallen through in any time. Let us take successively 2, 3, 4, 5, 6 seconds and we get—

$d = \frac{1}{2}g \times 4 = 16 \times 4 = 64$ feet in 2 seconds.
$d = \frac{1}{2}g \times 9 = 16 \times 9 = 144$,, 3 ,,
$d = \frac{1}{2}g \times 16 = 16 \times 16 = 256$,, 4 ,,
$d = \frac{1}{2}g \times 25 = 16 \times 25 = 400$,, 5 ,,
$d = \frac{1}{2}g \times 36 = 16 \times 36 = 576$,, 6 ,,

Since the distance through which a body falls in the first second of time from rest is 16 feet, while it falls through 64 feet in 2 seconds and 144 feet in 3 seconds, we find that it falls through 48 feet in the 2nd second and 80 feet in the 3rd second; these distances are each equal to the distance fallen through in the 1st second multiplied by its corresponding odd number.

Thus, taking 6 seconds as the time during which a body has been falling:

1 second 1 × 16 = 16 ft. in 1st second.
2 ,, 3 × 16 = 48 ,, 2nd ,,
3 ,, 5 × 16 = 80 ,, 3rd ,,
4 ,, 7 × 16 = 112 ,, 4th ,,
5 ,, 9 × 16 = 144 ,, 5th ,,
6 ,, 11 × 16 = 176 ,, 6th ,,

Adding these distances together, we get the distance fallen through in 6 seconds = 576 feet, which is the same as that given by formula (1).

$$16 \times 36 = 576 \text{ feet.}$$

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$$16 \times 36 = 576 \text{ feet.}$$

Finding Heights by Falling Bodies.—The height of a mast may be ascertained by dropping a bullet or other small body from the mast-head and noting the number of quarter seconds it takes to reach the deck. The square of the quarter seconds will be the height in feet.

A bullet is dropped from a ship's royal yard and strikes the deck after a lapse of 3 seconds, what is the height of the royal yard?

Here 3 seconds = 12 quarter seconds; therefore

$$12 \times 12 = 144 \text{ feet.}$$

Another bullet is dropped from the topgallant yard, and takes $2\frac{1}{2}$ seconds to reach the deck; this equals 10 quarter seconds, therefore

$$10 \times 10 = 100 \text{ feet.}$$

By a similar experiment the height of a tower or cliff may be found.

Centrifugal Force.—A simple example of centrifugal force is when a stone is made fast to a string and whirled round in a circle; the strain upon the string is the centrifugal force, which increases directly as the square of the velocity with which it moves and inversely as the length of the string which holds it in the circle. If the stone is moving with a uniform velocity in the circle and the string is shortened by being allowed to wind round the finger, the time of describing each revolution becomes shorter and shorter until the stone reaches the finger, while the centrifugal force increases in the same proportion that the length of the string decreases, the velocity remaining constant. If the tension on the string retaining the stone in the circle is at any time released the stone will fly off at a tangent to that point of the circle at which it is released, that is at a right angle to the direction of the string. The sailor heaving the lead knows this and lets go his hold of the line just as the lead passes under the bottom centre, or a little forward of a point perpendicularly under him, ~~so as to give it a good rise and enable it to fly well forward.~~ If he retains his hold on the line too long, the lead will rise upwards and may come down on his head, as the author has often seen happen.

The Sling.—The stone sling of the schoolboy is also a practical application of centrifugal force and is sometimes replaced by a simple bit of string made fast to a stone, which is let fly with the stone when the required velocity has been acquired, which carries it many times farther than it could be thrown by hand. Another illustration of centrifugal force practised by the schoolboy is a pitcher of water swung round in a vertical circle with such velocity that the water does not spill when the pitcher is overhead mouth downwards. The formula for finding the pull upon the string when the velocity and radius of the described circle are known, is

$$\text{Pull} = \frac{Wv^2}{gr} \qquad (1)$$

Otherwise stated

$$\text{Pull} = \frac{\text{Weight} \times (\text{velocity})^2}{\text{gravity} \times \text{radius.}}$$

When the radius of the circle and the time of describing a revolution are given, then we have the formula:

$$\text{Pull} = \frac{W}{g} = \frac{4\pi^2 r}{t^2}$$

Otherwise

$$\text{Pull} = \frac{\text{weight}}{\text{gravity}} \times \frac{4\,(3{\cdot}1416)^2 \times \text{radius}}{(\text{seconds})^2} \qquad (2)$$

Heaving the Lead.—For an example we will take the leadsman in the chains swinging the lead. The lead weighs 9 lbs.; the radius of the circle it describes is the distance from the shoulder of the sailor to the centre of gravity of the lead, which we will take equal to 9 feet. The lead makes a complete revolution in 2 seconds, which gives a velocity of 28·275 feet per second. From these data we will find the pull on the leadsman's arm by the first formula.

$$\text{Pull} = \frac{9 \times (28{\cdot}275)^2}{32 \times 9}$$

Here the 9 is cancelled, as it enters both numerator and denominator, hence we get

$$\text{Pull} = \frac{799{\cdot}475}{32} = 24{\cdot}984 \text{ lbs.}$$

This is the solution when the velocity and radius are given, without any knowledge of the time. We will now give the solution when the radius and time of revolution are given. In this example the time is 2 seconds, therefore by the second formula we get

$$\text{Pull} = \frac{9}{32} \times \frac{4 \times (3{\cdot}1416)^2 \times 9}{4}$$

$$= \frac{81 \times 9{\cdot}8696}{32} = 24{\cdot}984 \text{ lbs.}$$

If we know the breaking strain of a line which retains a given weight, revolving in a circle, we may find ~~from formula (1)~~ the velocity the weight has when the line breaks, ~~since the breaking strain will~~ be equal to the pull.

$$\frac{\text{Pull} \times g \times r}{w} = v^2$$

Otherwise, $$\text{Velocity}^2 = \frac{\text{pull} \times \text{gravity} \times \text{radius}}{\text{weight}}$$

Suppose in the above example the breaking strain of the lead line to be 112 lbs., what will be the velocity of the 9 lbs. lead when the line breaks?

$$\text{Velocity}^2 = \frac{112 \times 32 \times 9}{9}.$$

Therefore,

$$\text{Velocity} = \sqrt{112 \times 32} = 59{\cdot}86 \text{ feet per second.}$$

This velocity reduces the period of revolution to less than half the time it occupied when the pull was 24·982 lbs.; we therefore learn that the pull increases in the same proportion that the square of the time in seconds decreases, which we may verify. The time of revolution in the first case was 2 seconds, and the pull 24·982 lbs., while in the second case the pull was 112 lbs.

Therefore,

$$112 : 24{\cdot}982 :: 4 : [\text{time of revolution (second case)}].$$

$$\text{Time of revolution} = \sqrt{\frac{24{\cdot}982 \times 4}{112}} = \sqrt{0{\cdot}892} = 0{\cdot}945 \text{ sec.}$$

Now, the circumference of the circle described is $2 \times 9 \times 3{\cdot}1416 = 56{\cdot}5508$ feet, and the velocity is 59·86 feet; therefore the time of describing it is

$$= \frac{56{\cdot}5508}{59{\cdot}86} = 0{\cdot}945 \text{ second,}$$

which agrees with the former result.

The greatest horizontal distance to which the lead may be hove with any given velocity will be when the leadsman lets go the line at the instant when the lead has reached a point on the circle 45° from the plumb point below him; and its time of flight will be limited to the time which gravity would take to bring it down to the water. We may therefore find its time of flight, its horizontal range, and the height to which it will rise.

$$\text{The time in seconds} = \frac{2\ \text{velocity} \times \text{sin. } 45^\circ}{\text{gravity}}$$

Time of Flight.—For example, we will take the first case, where the velocity of the lead was 28·275 feet per second, and calculate the time of flight.

$$\text{Time in seconds} = \frac{2 \times 28{\cdot}275 \times \text{sin. } 45^\circ}{32}$$

As we have a sine here, we will make the calculation by logarithms.

	sin. 45° log.	9·8495
	2 „	0·3010
	28·275 „	1·4514
Arith. co.	32 „	8·4948
Time = 1·25^s	„	0·0967

Horizontal Range.—To find the horizontal range of the lead we consider it to move in a straight line, tangent to the circle at the point where it was let go, and with the velocity it had in the circle; this line will be the hypothenuse of a right-angled triangle, and will be equal in length to the velocity multiplied by the time; therefore,

$$\begin{aligned}\text{Horizontal range} &= \text{velocity} \times \text{time} \times \text{cos. } 45^\circ.\\ &= 28{\cdot}275 \times 1{\cdot}25 \times \text{cos. } 45^\circ.\end{aligned}$$

cos. 45 log.	9·8495
28·275 „	1·4514
1·25 „	0·0968
Hor. range = 24·99 feet log.	1·3977

Vertical Range.—The velocity with which the lead rises vertically upwards is equal to the velocity in the circle, multiplied by the sine of 45°; therefore,

$$\text{Vertical velocity} = 28{\cdot}275 \times \text{sin. } 45^\circ$$

	sin. 45° log.	9·8495
	28·275 „	1·4514
Vertical velocity	20 feet	1·3009

This is the initial velocity per second with which the lead rises vertically.

Formula (3) gives $\text{velocity}^2 = 2\ \text{gravity} \times \text{height}$.

Therefore, $20^2 = 2 \times 32 \times \text{height}$.

Height $= \frac{400}{64} = 6\frac{1}{4}$ feet, which is the highest point to which the lead would rise.

Taking the second case, where the velocity of the lead in the circle was 59·86 feet per second, and calculating the height to which it would rise, we get for the vertical velocity per second. Velocity multiplied by sin. 45° = 59·86 × sin. 45°

$$\begin{array}{rr} \text{sin. } 45^\circ \text{ log.} & 9{\cdot}8495 \\ 59{\cdot}86 \ \ \text{,,} & 1{\cdot}7771 \\ \hline \text{Vertical velocity} = 42{\cdot}33 \text{ ft. log.} & 1{\cdot}6266 \end{array}$$

Therefore, for the height to which the lead will rise we have

$$(42{\cdot}33)^2 = 2 \times 32 \times \text{height.}$$

Therefore,

$$\text{Height} = \frac{(42{\cdot}33)^2}{2 \times 32} = \frac{1792}{64} = 28 \text{ feet.}$$

This height is supposed to be measured from the surface of the water, which the lead just clears as it swings. The range and time of flight belong to the subject of projectiles rather than centrifugal force, but as the projectile force used for heaving the lead is generated by its motion in a circle, it has been introduced here.

By centrifugal force any body may be burst if only sufficient velocity can be given to it to overcome the cohesion of its substance. Grindstones sometimes burst under its influence. Ships' steering wheels are often burst by centrifugal force, when a heavy sea happens to strike the rudder, or the ship gets stern-way by being caught aback in a heavy gale and sea.

Energy. Potential Energy.—*Energy* is the capability of doing work. When a body or weight is in an elevated position, such as a boulder on the edge of a precipice, or a pile-driver at the top of its tower, it is said to possess *potential energy* equal to its weight in lbs., multiplied by the number of feet through which it can fall. Thus, if the boulder be rolled over the precipice, whose height is 300 feet, and the weight of the boulder is 10 tons, it will be capable of giving out—

$$10 \times 2240 \times 300 = 6{,}720{,}000 \text{ foot-lbs. of work.}$$

A pile-driver weighs 300 lbs., and is allowed to fall from a height of 30 feet, what is its energy when it strikes the pile?

$$\text{Energy} = 9000 \text{ foot-lbs.}$$

Therefore Potential energy = weight × height.

Kinetic Energy.—Kinetic energy is the energy which a body possesses by virtue of its motion, and is equal to half the mass of the body multiplied by the square of its velocity, the formula for which is—

$$\text{Kinetic energy} = \frac{\text{mass}}{2} \times \text{velocity.}^2$$

But in a former article the mass was shown to be equal to weight ÷ gravity; therefore, we get—

$$\text{Kinetic energy} = \frac{\text{weight}}{2 \text{ gravity}} \times \text{velocity.}^2$$

If a body weighing 10 lbs. falls through 16 feet, its capability of doing work due to potential energy is—

$$= 16 \times 10 = 160 \text{ foot-lbs.}$$

But 16 feet is the distance through which a body would fall in the first second of time from rest, and we have seen that the velocity acquired in one second is 32 feet. Being thus given the velocity of the same body, we may find its kinetic energy—

$$\text{Kinetic energy} = \frac{10 \times 32^2}{2 \times 32} = 160 \text{ foot-lbs.}$$

$$\text{Therefore weight} \times \text{height} = \frac{\text{weight} \times \text{velocity.}^2}{2 \times 32}$$

A piece of machinery is being hove out of a ship's hold, when the sling parts, letting the piece of iron, which weighs 15 cwt., fall through a height of 18 feet. What will be its energy when it reaches the bottom of the hold? Here we have given the weight and the height fallen through.

Therefore

$$\text{Potential energy} = 18 \times 15 = 270 \text{ foot-cwts.}$$

A topgallant-mast, weighing 12 cwt., is being sent up, when the mast-rope carries away, allowing the mast to fall through a height of 60 feet. With what energy will it strike the deck?

$$\text{Potential energy} = 12 \times 60 = 720 \text{ foot-cwts.}$$

A steamer is driving into a head sea at the rate of 14 knots when a solid sea comes over the bows, what would be the kinetic energy of a cubic foot of the water due to the ship's motion?

$$\text{Velocity of water} = \frac{14 \times 6080}{60 \times 60} = 23{\cdot}64 \text{ feet per second.}$$

The weight of a cubic foot of sea water is 64 lbs.

$$\text{Kinetic energy} = \frac{\text{weight}}{2 \times 32} \times \text{velocity.}^2$$

Therefore $\frac{64}{2 \times 32} \times (23{\cdot}64)^2 = 558{\cdot}8$ foot-lbs.

This represents the energy or capability of a cubic foot of water to do work on board when the vessel is going at the rate of 14 knots.

A Ship's Ramming Power.—A ship has a displacement of 6000 tons and a speed of 14 knots per hour. Her kinetic energy would therefore be equal to—

$$\frac{6000 \times (23{\cdot}64)^2}{64} \text{ foot-tons.}$$

23.64 is the velocity in feet per second at the speed of 14 knots

$$= \frac{14 \times 6080}{3600}$$

Hence we get—

$$\text{Kinetic energy} = \frac{6000 \times 558{\cdot}8}{64} = 52387{\cdot}5 \text{ foot tons.}$$

That is, a ship of 6000 tons displacement, moving at a speed of 14 knots per hour, would have stored up in her an accumulated energy of 52387·5 foot-tons, which means that her energy would be capable of raising 52387·5 tons through 1 foot or 1 ton through 52387·5 feet. Or, again, it would be equal to the energy of 6000 tons falling through a height of 8·7312 feet.

It is thus seen with what enormous force one ship may ram another when the thrust is given perpendicularly to the rammed ship's side. When the impact is made obliquely to the other ship's side then the kinetic energy of the ramming ship may be estimated from the formula

Effective impact = kinetic energy × sine of striking angle.

This impact is the component of the kinetic energy perpendicular to the rammed ship's side.

Let us suppose that the ship in the above example strikes another ship at an angle of 37°, and suppose, for convenience, that the rammed ship is stationary, we then get—

$$\text{Effective impact} = 52387{\cdot}5 \times \sin. 37^\circ.$$

		37°	sin. 9·779463
Kinetic energy	52387·5		log. 4·719227
Component	31527·5 foot tons		log. 4·498690

This gives for the force of the impact when made obliquely, 20860 foot-tons less than the impact when made perpendicularly to the ship's side. The pressure of the impact will act equally on both ships, but the rammed ship is likely to suffer more severely than the ramming one.

The rule for the collision of two free and inelastic bodies is:

*The momentum communicated from one to the other is their relative velocity multiplied by the product of their masses and divided by the sum of their masses, and this quotient divided by the time of the impact gives the mean pressure.**

Now, as ships are floating in water they cannot be considered as entirely free bodies, and it is difficult to tell how much the mass of each ship must be increased to represent the mass of water which each will cause to undergo a change of motion. Of course the ship which is rammed broadside on will have to move a much greater mass of water than the ramming ship, which strikes stem on, and which is free to recoil more readily from the impact. It is also difficult to tell the time during which the impact continues under the various phases of ship collision, but it may be inferred that the more obliquely they strike each other the shorter will be its duration and the less severe the damage done to both ships.

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* Perry's "Practical Mechanics."

RULES IN MENSURATION.

Useful Rules in Mensuration of Planes and Solids.— (1) To find the circumference of a circle, the diameter being given:

Multiply the diameter by 3·1416, *the product is the circumference.*

(2) To find the length of an arc of a circle to any radius:

Multiply the number of degrees, minutes, and seconds in the arc, expressed in degrees and decimals by ·017453 *and by the radius; the result will be the length of the arc in feet or inches, according as the radius is expressed in feet or inches.*

(3) To find the diameter of a circle from the circumference:

Multiply the circumference by ·3183, *the product will be the diameter.*

(4) To find the area of a circle:

Multiply the square of the diameter by ·7854, *the product will be the area.*

(5) To find the area of the sector of a circle:

Find the length of the arc by rule (2) *and divide it by* 2; *then multiply by the radius; the result will be the area.*

(6) To find the diameter of a circle from the area:

Divide the area by ·7854, *or multiply it by* 1·273, *and extract the square root; the result will be the diameter.*

(7) To find the area of a triangle:

Multiply the height by half the length of the base; the product will be the area.

(8) To find the curved surface of a cylinder:

Multiply the diameter by 3·1416 *and by the length of the cylinder; the product will be the curved surface.*

(9) To find the surface of a cone:

Multiply the slant height by half the circumference of the base.

(10) To find the surface of a sphere:

Multiply the square of the diameter by 3·1416, *or multiply the diameter by the circumference; in both cases the result will be the surface of the sphere.*

(11) To find the volume or content of a cylinder:

Multiply the square of the diameter by ·7854, *and this product by the length of the cylinder; the product will be the volume.*

(12) To find the volume of a cone:

Multiply the diameter of the base squared by ·7854, and this product by one-third the vertical height; the result is the volume.

(13) To find the volume of a sphere:

Multiply the cube of the diameter by ·5236; the product is the volume.

(14) To find the number of gallons a vessel will contain:

Find the volume by one of the preceding rules, which, if expressed in cubic feet, multiply by 6·24; but if expressed in cubic inches, multiply by ·00368; the result will be the contents in gallons in both cases.

(15) To find the area of an ellipse:

Multiply the greatest and least diameters together, and the product by ·7854; the result will be the area.

(16) To find the circumference of an ellipse:

Multiply half the sum of the two diameters by 3·1416, for the circumference nearly.

(17) To find the area of a parabola:

Multiply the height by the base; $\frac{2}{3}$ *of the product will be the area.*

(18) To find the volume of a paraboloid:

Multiply the square of the diameter by the height and the product by ·3927; the result will be the volume.

(19) To find roughly the volume or solid content of round timber:

Multiply the quarter of the mean girth or circumference by the diameter and by the length; the result will be the solid content.

To find the weight of a solid spherical shot or ball of iron when its diameter is given.

Spheres are to each other as the cubes of their diameters, and an iron ball of 4 inches diameter weighs 9 lbs.; from this we may find the weight of any other ball of given diameter; thus let d and w be the diameter and weight of any ball, we have the proportion:

$$4^3 : d^3 :: 9 : w,$$

or

$$64 : d^3 :: 9 : w,$$

Therefore,

$$w = \frac{9d^3}{64}$$

Rule.—*Multiply the diameter cubed by 9 and divide by 64; the quotient will be the weight of the ball in lbs.*

To find the diameter of an iron ball when the weight is given. We get from the above equation,

$$d^3 = 64\,\frac{w}{9} \therefore d = 4\sqrt[3]{\frac{w}{9}}$$

RULE.—*Divide the weight of the ball by 9 and find the cube root, which multiply by 4; the result will be the diameter of the ball.*

To find the weight of a leaden ball when the diameter is given: *Multiply the cube of the diameter by 2 and divide by 9*; the result *will be the weight in lbs.*

TABLE IX.—DIAMETERS, CIRCUMFERENCES AND AREAS OF CIRCLES.

Diameter.	Circumference.	Area.	Diameter.	Circumference.	Area.
1	3·1416	0·7854	5·75	18·0641	25·9672
1·25	3·9270	1·2272	6	18·8495	28·2743
1·5	4·7124	1·7671	6·25	19·6349	30·6796
1·75	5·4978	2·4053	6·5	20·4203	33·1831
2	6·2832	3·1416	6·75	21·2057	35·7847
2·25	7·0686	3·9761	7	21·9911	38·4846
2·5	7·8540	4·9087	7·25	22·7765	41·2825
2·75	8·6394	5·9396	7·5	23·5620	44·1786
3	9·4248	7·0686	7·75	24·3473	47·1730
3·25	10·2102	8·2058	8	25·1327	50·2655
3·5	10·9956	9·6211	8·25	25·9181	53·4592
3·75	11·7809	11·0446	8·5	26·7035	56·7450
4	12·5664	12·5664	8·75	27·4889	60·1320
4·25	13·3517	14·1862	9	28·2743	63·6172
4·5	14·1371	15·9043	9·25	29·0594	67·2006
4·75	14·9225	17·7205	9·5	29·8451	70·8822
5	15·7079	19·6349	9·75	30·6305	74·6619
5·25	16·4933	21·6475	10	31·4159	78·5398
5·5	17·2787	23·7583			

This table gives the circumferences and areas of circles, from diameter 1 unit to diameter 10 units; these units may have any value, such as a league, a mile, a fathom, a foot, an inch, or any decimal of an inch. Therefore, whatever unit may be used for the diameter, the circumference and area will be in terms of the same unit. For instance, if we require the area of a circle 30 inches in diameter, we find that if we multiply diameter 3 in the table by 10 and area 7·0686 by 10^2, we get diameter 30 and corresponding area = 706·86 square inches. Suppose we require the circumference to a circle 95 fathoms in diameter, move the decimal point to 9·5 one place to the right; also in the circumference one place to the right; but in the area move the decimal point two places to the right, because areas of circles vary as the squares of their diameter. Hence we get for diameter 95 fathoms, circum. = 298·451, area 7088·22 fathoms (square) and similarly for any other measure that comes within any figure in the table multiplied by 10 or 100.

From the same table may be found the curved surface and volume of a cylinder by simply multiplying the circumference of the cylinder by its height for the curved surface. And the area by its height, for the volume or solid content.

In a similar manner may be found the curved surface and volume of a right cone.

Multiply the circumference of the base from the table by half the slant height; the result will be the curved surface.

For the volume.—*Multiply the area corresponding to the diameter of the base by one-third the vertical height; the result will be the volume or solid content.*

To find the surface area of a sphere.—*Find the area of a circle having the same diameter and multiply this area by* 4; *the product will be the surface area of the sphere, since the surface of a sphere is equal to four times the area of one of its great circles.*

When the cylinders and cones are hollow and it is required to ascertain their capacity in gallons, if the capacity is given in cubic inches, multiply it by ·003595; the product will be the capacity in gallons. When the capacity is given in cubic feet, multiply it by 6·24; the product will be the capacity in gallons. These multipliers will enable the cubic capacity of any vessel whatever to be converted into gallons.

Table showing the areas and angles of polygons not exceeding 12 sides, viz.: the angle at the centre and the angle which the sides make with each other; also the area of the polygon when the sides are each equal to unity or 1:

TABLE X.

Number of Sides.	Name of Polygon.	Angle at Centre.	Angle between the Sides.	Area.
3	Trigon . .	120°	60°	0·433013
4	Tetragon . .	90°	90	1·000000
5	Pentagon . .	72	108	1·720477
6	Hexagon . .	60	120	2·598076
7	Heptagon . .	$51\frac{3}{7}$	$128\frac{4}{7}$	3·633912
8	Octagon . .	45	135	4·828427
9	Nonagon . .	40	140	6·181824
10	Decagon . .	36	144	7·694209
11	Undecagon .	$32\frac{8}{11}$	$147\frac{3}{11}$	9·3656[illegible]
12	Dodecagon .	30	150	11·1961[illegible]

For the area of any polygon up to 12 sides: *Multiply the square of the side by the area corresponding to the required polygon in the table; the product will be the area in any unit which measures the side.*

By means of Table X. the volumes of prisms and pyramids may also be calculated.

Find the area of the polygon having the same number of sides as the prism: *Multiply this area by the height of the prism; the result will be its volume.*

Find the area of the polygon having the same number of sides as the pyramid: *Multiply this area by one-third the height of the pyramid; the result will be its volume.*

TABLE XI.—DIAMETERS AND VOLUMES OF SPHERES.

Diameter.	Volume.	Diameter.	Volume.	Diameter.	Volume.
1	0·5236	4·25	40·1934	7·25	199·5276
1·25	1·0226	4·5	47·7120	7·5	220·8869
1·5	1·7671	4·75	56·1140	7·75	243·7213
1·75	2·8061	5	65·4486	8	268·0759
2	4·1886	5·25	75·7644	8·25	294·0021
2·25	5.9640	5·5	87·1118	8·5	321·5475
2·5	8·1810	5·75	99·5386	8·75	350·7613
2·75	10·8889	6	113·097	9	381·6956
3	14·1368	6·25	127·8284	9·25	414·3943
3·25	17·9737	6·5	143·7889	9·5	448·9103
3·5	22·4487	6·75	161·0275	9·75	485·2910
3·75	27·6109	7	179·594	10	523·5831
4	33·5095				

If the diameters are multiplied by 10, the volume will be multiplied by 1000—*i.e.*, if the decimal point in the diameter is moved one place to the right hand—the decimal point in the volume must be moved three places to the right. Any unit may be adopted which will bring the diameter within the limits of the table.

If it is desired to find the volume of a cylinder having its diameter and height equal, it is only necessary to take the volume of the sphere having the same diameter from the table and add to it the half of itself, the sum will be the volume of the circumscribing cylinder, since every sphere is equal to two-thirds of the circumscribing cylinder.

To find from the table the volume of a cone whose vertical height is equal to the diameter of its base: *Take half the volume* *of the sphere having a diameter equal to that of the base of the cone; this will be the volume of the cone, since a cone is equal to one-third the volume of its circumscribing cylinder.*

When the weight of a body is required from its volume expressed in cubic feet or inches: *Find the weight of a cubic foot or cubic inch of the substance from Table VI. and multiply it by the volume; the product will be the weight of the body in lbs.*

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